Herring Stock Estimates from Diving Surveys of Spawn for Georgia Strait in 1986

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PREFACE

An early draft of this manuscript was presented at the September 1986 Herring Stock Assessment Committee meeting. At that time, spawner biomass estimates were made using a model which predicts egg density from visual observations and spawn sample weights. Since then, eggs in preserved spawn samples have been counted and the results were used in this analysis. Spawner biomass estimates are approximately 39% greater than those presented in September 1986.

ABSTRACT

Schweigert, J. F. and C. W. Haegele. 1988. Herring stock estimates from diving surveys of spawn for Georgia Strait in 1986. Can. MS Rep. Fish. Aquat. Sci. 1971: 65 p.

Using the results of diving surveys of spawn, we estimated that 60,212 tonnes of herring spawned in Georgia Strait in 1986. In Area 14, 51,092 tonnes were estimated to have spawned on Denman and Hornby islands and along the Vancouver Island shoreline from below Deep Bay to below Little Qualicum River. In Area 15, 1141 tonnes were estimated to have spawned on Harwood and Savary islands. An estimated 7934 tonnes spawned in Area 17: 152 tonnes in Nanoose Bay, 332 tonnes at Icarus Point, 105 tonnes at Sharpe Point and 7344 tonnes along the Vancouver Island shoreline from above Boat Harbour to Coffin Point. Only 46 tonnes were estimated to have spawned in Area 18. All major spawns were surveyed by divers and surface survey results were used to estimate the spawning biomass for the minor spawns.

Estimates of egg density from a predictive model based on sample weight and egg layers were uniformly low in 1986 relative to earlier years. Model predictions have generally been fairly accurate for Georgia Strait spawns and the low estimates for this year appear to result from low estimates of egg layers on the various vegetation substrates.

The spawns were wider and on more gently sloping beaches in Area 14 than in Area 17. Most of the spawn was deposited between 1 m above to 3 m below chart datum. Egg density declined with depth in Area 14 but not Area 17. Sea grasses and the brown algae, Sargassum muticum, were the most common vegetation type for egg deposition in Area 17, while rockweed and filamentous red algae were more commonly used in Area 14.

RESUME

Schweigert, J. F. and C. W. Haegele. 1988. Herring stock estimates from diving surveys of spawn for Georgia Strait in 1986. Can. MS Rep. Fish. Aquat. Sci. 1971: 65 p.

En nous servant des résultats de relevés du frai effectués sous l'eau, nous avons estimé à 60 212 tonnes le hareng qui a frayé dans le détroit de Géorgie en 1986. Dans la zone 14, on a estimé à 51 092 tonnes le hareng qui a frayé aux îles Denman et Hornby et le long du littoral de l'île Vancouver d'un point situé au-dessous de la baie Deep jusqu'à un point situé au-dessous de la rivière Little Qualicum. Dans la zone 15, on a évalué à 1141 tonnes le hareng qui a frayé aux îles Harwood et Savary. On estimé que 7934 tonnes de hareng ont frayé dans la zone 17: 152 tonnes dans la baie Nanoose, 332 tonnes a la pointe Icarus, 105 tonnes a la pointe Sharpe et 7344 tonnes le long du littoral de l'île Vancouver d'un point situé au-dessus de Boat Harbour jusqu'a a la pointe Coffin. On a évalué à 46 tonnes seulement le hareng qui a frayé dans la zone 18. Des plongeurs ont effectué des relevés des principales pontes et on s'est servi des résultats des relevés de surface pour estimer la biomasse des géniteurs pour les petites pontes.

Les estimations de la densité des oeufs faites à partir d'un modèle de prédiction basé sur le poids des échantillons et les couches d'oeufs ont été uniformément basses en 1986 par rapport aux années précédentes. Les prédictions selon le modèle ont généralement été assez précises pour les pontes dans le détroit de Géorgie et les faibles estimations pour cette année semblent découler des faibles estimations des couches d'oeufs sur les divers substrats de végétation.

Les frayères étaient plus larges et sur des plages à pente plus douce dans la zone 14 que dans la zone 17. La plus grande partie des oeufs a été déposée entre 1 m au-dessus et 3 m au-dessous du zéro des cartes. La densité des oeufs diminuait avec la profondeur dans la zone 14 mais non dans la zone 17. Les zostères et l'algue brune Sargassum muticum constituaient le type de végétation le plus répandu pour le dépot des oeufs dans la zone 17, alors que le fucus et les algues rouges filamenteuses e'taient les plantes marines les plus couramment utilisées dans la zone 14.

INTRODUCTION

Herring stocks in Georgia Strait appear to have declined over the past several years (Haist et al. 1986). Herring spawns in Georgia Strait were surveyed by divers in 1985 (Schweigert and Haegele 1988) to directly estimate adult spawner biomass, independently from stock assessment models (Haist et al. 1986). Georgia Strait was closed to herring roe fishing in 1986 and a diving survey of spawns was again conducted in 1986 to monitor the rate and magnitude of stock recoveries. The results of the 1986 diving survey of Georgia Strait are presented in this report.

METHODS

Herring spawns were surveyed either by SCUBA divers or by traditional surface survey techniques. In the surface survey, visual observations were made from the surface. Frequently a viewing box was used to increase the visibility of the bottom. Grapples were used to detect and obtain samples of spawn. From these observations, the length and width of spawn and the layers of eggs were estimated. The proportion of the area of the spawn devoid of eggs or vegetation (bare area) was also estimated. Information on the type of vegetation on which the eggs were deposited was also obtained but not used in this report.

The diving survey followed a two-stage sampling design (Schweigert et al. 1985). Transects perpendicular to the shore were the primary sampling unit and 0.5 sq. m quadrats sampled along the transect were the secondary sampling unit. Samples consisted of all the rooted or attached vegetation, and the eggs adhering to it, within the quadrat. Layers of eggs, percent cover of the vegetation, and the dominant vegetation class were estimated by divers for each quadrat. Samples were weighed and weighed subsamples were preserved in Gilson's fluid for subsequent egg counts. Eggs on the bottom substrate were estimated from diver estimates of layers of eggs and percent of bottom covered by vegetation (Haegele et al. 1979) and added to eggs on vegetation. Depths at sample sites were measured by divers and were corrected to chart datum using water levels observed at applicable tide gauge installations (Tides and Currents, Institute of Ocean Sciences, Sidney, B.C.).

Transects were established at nearly equal intervals along the length of the spawn and samples were collected at equal intervals along each transect with the spacing determined by the width of the spawn. The mean egg density and 95% confidence interval were calculated for each spawn and transect means were weighted by transect lengths (Schweigert et al. 1985). The inner and outer edge of spawns were determined from measurements along transects. The limits of a spawn beyond the outer transects was determined by exploratory dives. This information was plotted on maps of marine vegetation

at scales of 1:4800 and 1:6000 (Haegele 1978; Haegele and Hamey 1979, 1981), the boundaries of the spawn contoured, and the area of the spawn measured. Spawner biomass (tonnes) was estimated as the product of spawn area, egg density, and 0.00000001, which reflects an assumed 200 eggs per gm female weight (Hay 1985) and a 1:1 sex ratio.

For spawns surveyed only from the surface, the observed length and an adjusted width was used to calculate area. Egg density was estimated from egg layer estimates. The equations and parameter estimates for these adjustments are given by Haist et al. (1986):

$$(1)\quad Width_{adj} = \exp\,[0.375\ \log_e (Width_{obs}) + 3.401]$$

$$(2)\quad Eggs \cdot m^{-2} = 75.861 + 105.321 \cdot Lay_{av}$$

To investigate discrepancies in egg density estimates between egg counts and model predictions, we calculated the mean, mode, and 25 and 75 percent quartiles for observed egg layers, sample weight, percent cover of vegetation, observed egg density, and predicted egg density for Area 14 and 17 by vegetation class for all years such data is available.

RESULTS

BIOMASS ESTIMATES

It was estimated from spawn surveys that 60,212 tonnes of herring spawned in Georgia Strait in 1986 (Fig. 1). Some spawning occurred in all four Statistical Areas (14, 15, 17, and 18) but 85% occurred in Area 14. We describe the individual spawns in each of these Areas below.

Area 14

There were three spawnings in Area 14 in 1986. On Denman Island, herring spawned from Longbeak Point at the northern tip (Fig. 2) along the eastern shoreline at Komas Bluff (Fig. 3), Fillongley Park (Fig. 4), and Whalebone Point (Fig. 5) to the southern tip at Boyle Point (Fig. 6) from March 9 to 20. This spawning area was 21.5 km long and covered 375.9 ha (Table 1) at an average egg density of 643,418 eggs per sq. m for a 24,185 tonnes spawner estimate (Table 2). On Hornby Island, herring spawned from March 14 to 21. The spawning was 21.9 km long, covered 222.8 ha (Table 1) and nearly circumscribed the island, occurring from Shingle Spit (Fig. 5) to Collishaw Point (Fig. 7), past Tralee Point to Whaling Station Bay (Fig. 9), missing Tribune Bay, and resuming at Dunlop Point to Norman Point (Fig. 10). Egg density was heavy at 976,221 eggs per sq. m and 21,749 tonnes were

estimated to have spawned on Hornby Island (Table 2). The Qualicum spawning on the Vancouver Island shoreline occurred from March 14 to 23 and began below Deep Bay (Fig. 11), from where it continued past Thames Creek (Fig. 12) to Nile Creek (Fig. 13) and past the Big Qualicum River (Fig 14). Spawn resumed west of the Little Qualicum River (Fig. 15) and continued eastward of the river for about 3 km (Fig. 16). The Qualicum spawning was 16.0 km long and covered 171.5 ha (Table 1). Egg density was lower here (300,715 eggs per sq. m) than on Denman and Hornby islands. We estimated that 5158 tonnes spawned at Qualicum (Table 2).

Area 15

Herring spawned on Savary and Harwood islands on March 15 and 24, respectively. Neither spawning area was surveyed by divers since surface surveys indicated that both were small and light (Table 1). The Harwood Island spawning was estimated from these reports to have been deposited by 300 tonnes and the Savary Island spawning by 841 tonnes, for an Area 15 total of 1141 tonnes (Table 2).

Area 17

The major spawning centered at Yellow Point was surveyed by divers while three late spawnings were only surveyed from the surface. Herring spawned at Yellow Point from March 16 to 20, in Nanoose Bay on April 4 and 9, at Icarus Point on April 4 and 5, and at Sharpe Point on April 10. The Yellow Point spawning occurred on Vancouver Island from north of Boat Harbour (Fig. 17), past Yellow Point (Fig. 18) into Kulleet Bay (Fig. 19) and south to Coffin Point (Fig. 20). This spawning area was 17.5 km long, occupied 108.6 ha, and, at an egg density of 676,592 eggs per sq. m, was deposited by 7344 tonnes (Table 1 and 2). The three later spawnings ranged from 0.7 to 2.0 km in length, from 5.8 to 23.9 ha in area, and from 139,000 to 233,000 eggs per sq. m in egg density (Table 1 and 2). The Nanoose Bay spawn was estimated to have been deposited by 152 tonnes, the Icarus Point spawn by 332 tonnes, and the Sharpe Point spawn by 105 tonnes. The total egg deposition in Area 17 was estimated to have been produced by 7933 tonnes of spawners.

Area 18

The earliest spawning in Georgia Strait occurred in Annette Inlet on Prevost Island on March 6. It was a very light spawning with egg density estimated at 18,222 eggs per sq. m. Because egg counts from samples were not available we used a model modified from that of Schweigert and Fournier (1982) to predict eggs per sq. m from quadrat observations on vegetation type, percent cover of vegetation, egg layers, and sample weight. Although the spawning area was 3.4 km long and occupied 25.3 ha, it was estimated to have been deposited by only 46 tonnes of fish (Table 2).

MODEL PREDICTIONS

The predictive model referred to earlier underestimated egg density in 1986 for all six vegetation classes (Table 6). In general, the modes for all the variables examined are lower than the means, suggesting non-normal and generally skewed distributions. However, a comparison of means, modes, and 25 and 75 percent quartiles should give a good indication of the range of values for each variable. Stock assessment data indicate that the stock size in Area 14 in 1981 was similar to 1986. Levels for 1983 and 1985 should be lower than for these years. Area 17 assessments indicate that 1986 stock size is larger than for 1985.

The means estimated for egg layers and sample weight reflect this trend for most of the vegetation types. Only for filamentous red algae are the estimates of egg layers in Area 14 higher in 1985 than in 1986. It is clear that the estimates of egg layers for all the vegetation classes is very similar in 1986 to what it had been in 1981 and yet the sample weight and egg count was much greater in 1986 than what it had been in 1981. Observed and predicted egg numbers are most disparate in 1986 for all vegetation classes. Predictions for 1985 appear to be slightly high but we had experienced difficulties in separating eggs and vegetation and many of these eggs were broken in processing resulting in underestimates of egg numbers. Data from Area 17, where available, generally support the results from Area 14.

SPAWN DISTRIBUTION

The distribution of spawn was determined for the two major Statistical Areas, 14 and 17. Spawn was wider ($P < 1\%$, Student t-test) in Area 14 than Area 17 (Fig. 21). Average transect length was 132 m in Area 14 and the three spawns had similar transect lengths: 147 m at Denman Island, 115 m at Hornby Island, and 124 m at Qualicum. The Yellow Point average transect length was 35 m. Beach slope was the probable cause for this width difference since depths at which spawns were deposited was similar for Area 14 and 17 (Fig. 21). Beach slope in Area 17 was 0.1277, a rise of 12.8 m every 100 m, while beach slope in Area 14 was 0.0506. The average inner edge of spawn was similar in Area 14 and 17 at 1.0 and 0.9 m above chart datum, respectively, while the outer edge of spawn was 2.5 and 2.1 m below chart datum, respectively. Hence spawn was deposited over an approximate average depth range of 3.5 m. The maximum depth to which spawn was deposited was 6.5 m below chart datum.

The type of vegetation on which the eggs were deposited, the mean (Wilcoxon median) percent cover of the vegetation, the mean layers of eggs, the mean egg density, and the mean sample weight were determined by depth interval. Depth intervals chosen were intertidal (above 0 m Chart Datum), upper subtidal (between 0 and 3 m below chart datum), middle subtidal (between 3 m and 6 m below chart datum), and lower subtidal (deeper than 6 m below chart datum). In the intertidal interval, rockweed, other brown algae

(Sargassum muticum) and filamentous red algae were the most common vegetation. Sea grasses, other brown algae, and foliose and filamentous red algae were the most common vegetation in the upper subtidal interval (Fig. 22). In the middle subtidal interval, spawn was mostly on filamentous red algae while there was no spawn in the lower subtidal interval. The vegetation differed significantly between depth intervals only at Denman Island and at Yellow Point ($P < 1\%$ for Denman Island and $P < 5\%$ for Yellow Point, Chi-square). The vegetation differed significantly between Area 14 and 17 in the upper two depth intervals ($P < 1\%$, Chi-square) with the frequency of sea grasses and other brown algae greater than expected in Area 17 and the frequency of rockweed and filamentous red algae greater than expected in Area 14.

The percent cover of the vegetation decreased with depth for all spawns (Fig. 23), but only at Qualicum was the difference significant ($P < 1\%$, Mann-Whitney test). Egg layers, egg density and sample weight decreased with depth for all spawns in Area 14, but not at Yellow Point (Fig. 23). The difference was significant for all three measures at Denman Island between the intertidal and middle subtidal interval and at Hornby Island between the intertidal and upper subtidal interval. Although egg layers were not significantly lower in the subtidal intervals than the intertidal interval at Qualicum, both egg density and sample weight were significantly lower in the upper subtidal interval than in the intertidal interval. This is probably due to the above noted lower percent cover of vegetation in the upper subtidal interval at Qualicum.

In Area 14, 37% of the spawn area was in the intertidal interval and 47% was in the upper subtidal interval (Fig. 24). In Area 17, 33% of the spawn area was in the intertidal interval and 60% of the spawn area in the upper subtidal interval. However, 52% of the eggs in Area 14 were deposited in the intertidal interval, because of the higher egg density there, while only 28% of the eggs were deposited in the intertidal interval in Area 17 because egg density was lower in the intertidal interval than in the upper subtidal interval (Fig. 24).

DISCUSSION

An important objective of the diver spawn survey research conducted at the Pacific Biological Station over the past decade has been to develop a survey methodology to visually assess herring spawns to estimate stock abundance for management of the resource. For the methodology to be useful it must be possible to develop models that may be used to estimate egg densities from variables that can be readily assessed visually such as layers of eggs and percent cover of vegetation. We have found that although it is possible to do this, these estimates are more variable than those obtained from the weight of spawn samples collected from the quadrats (Schweigert et al. MS). The other important consideration is that these variables be readily standardized so that they can be collected in a routine and unbiased fashion

over time. Although there is a learning period required, it appears that some of these variables may not be as readily assessed as one would have expected. In particular, it seems that the assessment of egg layers in Georgia Strait during the 1986 survey differed in some manner from what had been done in the past. If one assumes that there is a consistent positive relationship between egg numbers and sample weight and egg layers, then, as the egg numbers and sample weight increase, so should the estimate of egg layers. Clearly, this did not occur for the 1985 and 1986 data on sea grasses, other brown algae, and foliose and filamentous red algae. The sample weights and egg counts increased dramatically relative to 1981 and 1983, while egg layers did not increase significantly enough to reflect these increases. It appears that some further evaluation of the visual survey methodology is required in dealing with heavy spawns to more accurately reflect actual egg densities. It also suggests that if the visual survey technique is to be used on an ongoing basis to assess spawns, a small number of samples should be collected for egg counts to ensure accurate calibration of the visual spawn density estimates.

The confidence intervals (95%) for egg densities from egg counts were between 28% (Yellow Point) and 53% (Hornby Island) of the mean for individual spawns (Table 2) and 31% for Area 14 (Table 3). Sums of spawner biomass for individual spawns were nearly identical to biomass estimates using area means (Table 3). Hence, despite the occasional high variance, spawner biomass estimates for individual spawns are probably quite reasonable.

The high variance in some of the estimates may be the result of insufficient sampling. The sampling design for a minimum of 5 samples per transect was approached or exceeded for all spawnings, but the requirement for 4 transects per km was never achieved (Table 4), due mainly to time constraints. However, the optimal samples per transect (after Schweigert et al. 1985) was exceeded for all spawnings except that at Yellow Point, where the 95% confidence interval was within 28% of the mean. The optimal transects per km was exceeded for all but the Hornby Island spawning, where the 95% confidence interval was the broadest at 53% of the mean. Hence, insufficient transects may have been the cause for the high variance.

The distribution of spawn by depth was similar to that documented in diving surveys in the Georgia Strait in 1985 (Schweigert and Haegele 1988). That is, percent cover of vegetation, layers of eggs, and egg density decline with depth. Most spawn in Georgia Strait is deposited higher than 3 m below chart datum, but most spawn does not extend higher than 1 m above chart datum. Since low tides never fell below 1 m above chart datum during the egg incubation period in 1986, very little of the spawn became exposed at low tide. There were some between Area differences in spawn distribution, mostly dictated by beach slope and the attendant vegetation differences. The beach slope was steeper in Area 17 than in Area 14 and consequently spawnings were narrower in Area 17.

For the two spawnings, Denman Island and Yellow Point, that occurred in the same location and that were of approximately the same length in 1985 and 1986, there were no significant ($P < 5\%$, Student t-test) between year differences in observed beach slope, which is unlikely to change, or in the average inner or outer edge of spawnings. However, spawn width (i.e. transect

length) was significantly narrower at Yellow Point in 1986 at 35 m, compared to an average transect length of 67 m in 1985. This is probably the result of a slightly steeper slope observed in 1986 (0.1277) than in 1985 (0.0958) due to transect placement and a slightly greater depth range over which eggs were deposited in 1985. In 1985 the average inner and outer edge of spawn was 1.1 m above and 2.9 m below chart datum, respectively, while in 1985 the range was from 0.9 m above to 2.9 m below chart datum. The average transect length at Denman Island did not differ significantly between 1985 and 1986. Egg density in the intertidal interval was not significantly different between 1985 and 1986 at either Denman Island or Yellow Point (Schweigert and Haegele 1988). However, egg density was significantly higher ($P < 1\%$, Mann-Whitney test) in 1986 than 1985 at both of these locations in the upper subtidal zone. The egg density at Denman Island was 752,870 eggs per sq. m in 1986 and 265,200 eggs per sq. m in 1985 in the upper subtidal interval. The egg layers were similar in the two years, but percent cover of vegetation was significantly higher in 1986, 62.5 vs. 47.5. The egg density at Yellow Point was 778,004 eggs per sq. m in 1986 compared to 274,060 eggs per sq. m in 1985 in the upper subtidal zone. Here, the percent cover of the vegetation was similar between the two years but egg layers were significantly higher in 1986, 2.65 layers vs 1.55 layers. One may argue that this is the result of limits imposed by available vegetation surface area. In 1986, when stocks were more abundant, more fish spawned in a given section of beach. At Denman Island, where the available vegetation, as measured by percent cover, had remained stable, this resulted in thicker egg deposition, in terms of egg layers. At Yellow Point, where the vegetation was more abundant (higher percent cover) in 1986, the same result was achieved without increased egg thickness.

Herring spawning stocks in Georgia Strait nearly doubled in 1986 over stock sizes estimated in 1985 (Schweigert and Haegele 1988), indicating good recruitment. The bulk of the increase was in Area 14, where stocks increased from 23,082 tonnes to 51,092 tonnes (Table 5). Spawn length, area of spawn, and egg density all increased in Area 14. Specifically, spawn at Hornby Island increased considerably in both length, area, and egg density; spawn at Denman Island increased in egg density, and spawn at Qualicum increased in length and area. In Area 15, there was a 30% decline in spawn, with no spawn observed along the mainland shore at Atrevida Reef in 1986. In Area 17, stocks spawning at Yellow Point increased by about 32% and this increase was due to increased egg density, since both length and area of spawn declined. There was no spawn observed at Thetis Island in 1986, but there were several second wave spawns observed that did not occur in 1985. These amounted to 589 tonnes of spawners, which deposited their eggs in localities that are traditional spawning grounds, Nanoose Bay and Icarus Point (Haegele and Fitzpatrick 1983), but were not utilized in 1985. The Area 18 stocks remained at a very low level and may be on the verge of entirely disappearing.

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Table 1. Spawn survey results, from data collected by divers and Fishery Officers, for Georgia Strait in 1986. [Adjusted area = length • width • (100 - % bare)].

Location	Diving survey					Surface survey					
	No. of transects	Length (m)	Av. transect length (m)	Area (ha)	Av. egg layers	No. of patches	Length (m)	Av. width (m)	Raw area (ha)	Adjusted area (ha)	Av. egg layers
Area 14											
Denman I.	27	21500	147.35	375.891	1.75	12	21030	85.57	189.760	85.626	2.18
Hornby I.	19	21850	110.74	222.793	2.06	12	20050	37.82	66.025	41.469	3.16
Qualicum	14	15950	124.14	171.527	1.04	No survey					
Area 15											
Harwood I.	No survey					1	1800	20.00	3.600	2.160	1.00
Savary I.	No survey					1	800	800.00	64.000	44.800	2.00
Area 17											
Nanoose B.	No survey					2	700	20.56	1.350	0.915	1.49
Icarus Pt.	No survey					2	2000	40.00	8.000	5.100	0.60
Yellow Pt.	18	17500	34.50	108.554	2.90	18	16800	20.51	34.455	26.077	4.91
Sharpe Pt.	No survey					2	900	7.56	0.680	0.428	1.01
Area 18											
Annette In.	3	3400	74.33	25.300	0.28	No survey					

Table 2. Estimates of spawner biomass by individual spawn for Georgia Strait in 1986. (95% confidence intervals are given in brackets.)

Location	Source (T = transect no.)	Area (ha)	Thousands of eggs per sq. m	Tonnes of Spawners
Area 14				
Denman I.	T 1-7,10-22,31,33,35,37,39,41,44	375.891	643 (437 to 850)	24185 (16429 to 31942)
Hornby I.	T 2-17,20,21,31,32	222.793	976 (462 to 1491)	21749 (10288 to 33211)
Qualicum	T 3-8,10-12,18-21,23	171.527	301 (177 to 424)	5158 (3045 to 7272)
Area 15				
Harwood I.	Surface survey	16.570(a)	181(a)	300 (-)
Savary I.	Surface survey	29.371(a)	286(a)	841 (-)
Area 17				
Nanoose B.	Surface survey	6.511(a)	233(a)	152 (-)
Icarus Pt.	Surface survey	23.876(a)	139(a)	332 (-)
Yellow Pt.	T 1-8,10,12-20	108.554	677 (489 to 864)	7344 (5307 to 9383)
Sharpe Pt.	Surface survey	5.752(a)	182	105 (-)
Area 18				
Annette In.	T 1-3	25.300	18(b)	46 (-)

(a) Area calculated from F.O. observed length and F.O observed width, adjusted using equation (1), and egg density estimated from F.O observed egg layers using equation (2).
(b) Egg density estimated using biomass model (after Schweigert and Fournier 1981).

Table 3. Summary of spawn length and area, and estimates of spawner biomass using statistical area mean egg densities, for the Strait of Georgia in 1986. These estimates are compared to estimates derived by summing results for individual spawns from Table 2.

Statistical Area	Length (m)	Area (ha)	Thousands of eggs per sq. m (95% C.I.)	Tonnes (95% C.I.)	Tonnes (sum)
14	59300	770.211	657 (452 to 862)	50607 (34835 to 66378)	51092
15	2600	45.941	-	1141(a)	1141
17	21100	144.693	677 (489 to 864)	9790 (7074 to 12506)	7933
18	3400	25.300	18 (-)	46 (-)	46
Total	86400	986.145		61584	60212

(a) From Table 2.

Table 4. Estimated optimal sampling design to achieve a SE of 25% of the mean (after Schweigert et al. 1985) and achieved sampling density for 1986 diving surveys of herring spawn in Georgia Strait.

Location	Samples per transect	Spawn width (m) (area/length)	Achieved sampling fraction	Optimal sampling fraction	Achieved transects per km	Optimal transects per km
Denman I.	6.8	174.8	0.039	0.034	0.827	0.811
Hornby I.	5.6	102.0	0.055	0.029	1.150	1.477
Qualicum	7.4	107.5	0.068	0.046	1.139	0.957
Yellow Pt.	4.7	62.0	0.075	0.113	0.972	0.522
Area 14	6.1	111.5	0.055	0.031	0.891	0.574

Table 5. Comparison of herring spawn and adult herring biomass estimates from diving surveys for the Strait of Georgia in 1985 and 1986.

Location	Year	Length (m)	Av. tran. len. (m)	Area (ha)	Av. egg layers	Thousands of eggs per sq. m	Spawners (t)	Catch (t)	Adult biomass (t)
Area 14									
Denman I.	1985	20100	178	338.4	0.5	403	13647	-	-
	1986	21500	147	375.9	1.8	643	24185	-	-
Hornby I.	1985	6900	57	34.3	0.2	69	238	-	-
	1986	21850	111	222.8	2.1	976	21749	-	-
Qualicum	1985(a)	6100	159	96.9	1.8	272	2632	-	-
	1986	15950	124	171.5	1.0	301	5158	-	-
Sum Area 14	1985	33100	-	469.6	-	-	16517	6565	23082
	1986	59300	-	770.2	-	-	51092	0	51092
Area 15									
Harwood I.	1985	3000	92	38.2	0.4	164	628	-	-
	1986(a)	1800	92	16.6	1.0	181	300	-	-
Savary I.	1985	800	82	15.7	0.3	48	76	-	-
	1986(a)	800	367	29.4	2.0	286	841	-	-
Atrevida Rf.	1985	7200	49	47.4	0.4	192	910	-	-
	1986	0	0	0.0	0.0	0	0	-	-
Sum Area 15	1985	11000	-	101.3	-	-	1614	0	1614
	1986	2600	-	45.9	-	-	1141	0	1141
Area 17									
Thetis I.	1985	3200	48	11.4	0.6	113	128	-	-
	1986	0	0	0.0	0.0	0	0	-	-
Yellow Pt.	1985	21000	67	133.1	0.5	419	5579	-	-
	1986	17500	35	108.6	2.9	677	7344	-	-
Other V.I.	1985	0	0	0.0	0.0	0	0	-	-
	1986(a)	3600	100	36.1	0.8	163	589	-	-
Sum Area 17	1985	24200	-	144.5	-	-	5707	0	5707
	1986	21100	-	144.7	-	-	7933	0	7933

Table 5 (cont'd).

Location	Year	Length (m)	Av. tran. len. (m)	Area (ha)	Av. egg layers	Thousands of eggs per sq. m	Spawners (t)	Catch (t)	Adult biomass (t)
Area 18									
Selby Cove	1985(a)	550	130	7.2	<0.0	34	25	-	-
	1986	0	0	0.0	0.0	0	0	-	-
Annette In.	1985(a)	2050	199	40.7	<0.0	34	140	-	-
	1986	3400	75	25.3	0.3	18	46	-	-
Sum Area 18	1985	2600	-	47.9	-	-	165	0	165
	1986	3400	-	25.3	-	-	46	0	46
Sum S of G	1985	70900	-	763.3	-	-	24003	6565	30568
	1986	86400	-	986.1	-	-	60212	0	60212

(a) Based partially or entirely on F.O. surface data.

Table 6. Comparison of egg layers, sample weight, percent cover, observed and predicted egg density (in thousands of eggs per sq. m) for Strait of Georgia spawns from 1981-86.

	Egg layers				Sample weight (g)				% cover		Obs. density			Pred. density		
	N	Mean	Mode	Q1	Q3	Mean	Mode	Q1	Q3	Mean	Mode	Mean	Q1	Q3	Mean	Q1	Q3
Sea Grasses																	
Area 14-1981	135	1.73	2.00	0.80	2.00	1558	57	615	2163	69	80	262	21	417	293	103	427
Area 14-1983	206	1.11	0.10	0.20	2.00	977	262	299	1459	45	25	191	24	266	237	51	359
Area 14-1985	30	0.90	0.10	0.18	1.50	1188	66	324	1850	42	20	270	18	406	204	38	340
Area 14-1986	25	1.28	0.10	0.50	2.00	1599	1230	881	2199	71	90	434	127	716	284	137	398
Area 17-1985	44	0.90	0.20	0.25	1.50	1384	192	475	2232	67	75	280	17	432	237	62	375
Area 17-1986	13	0.94	1.50	0.45	1.50	1658	391	762	2229	73	90	468	187	381	277	124	390
Rockweed																	
Area 14-1981	7	0.83	0.10	0.10	1.50	713	8	16	1290	42	5	84	0	190	93	1	156
Area 14-1983	18	0.59	0.10	0.10	1.00	771	54	109	772	26	5	20	0	29	94	9	91
Area 14-1985	8	0.62	0.10	0.10	0.87	782	38	160	504	34	5	31	0	27	89	15	44
Area 14-1986	23	0.94	0.30	0.30	1.50	2079	328	1170	2226	66	50	322	82	287	255	118	255
Area 17-1985	16	0.86	1.00	0.75	1.00	435	83	153	615	86	100	90	3	158	435	153	615
Kelp																	
Area 14-1981	21	1.31	1.00	0.50	2.00	1329	214	662	1683	52	50	75	2	81	167	79	198
Area 14-1983	31	0.34	0.10	0.10	0.50	880	78	389	984	27	30	56	6	42	103	33	121
Area 14-1985	12	0.71	0.25	0.25	1.37	1757	110	595	3534	55	100	78	7	103	198	68	404
Area 14-1986	5	1.36	1.00	0.40	2.50	2940	991	1264	5261	82	100	626	48	1470	383	140	737
Area 17-1985	9	0.84	0.20	0.45	1.22	1445	292	653	2261	62	55	43	1	78	171	70	272
Other Brown Algae																	
Area 14-1981	40	3.31	4.00	2.00	4.75	1860	76	453	2896	61	60	390	27	657	325	87	490
Area 14-1983	93	2.48	1.50	1.00	3.50	1708	357	345	2631	32	10	214	22	269	325	60	517
Area 14-1985	41	2.19	0.10	0.35	3.50	3852	224	825	4197	46	30	650	23	516	658	98	674
Area 14-1986	65	3.75	1.50	1.50	5.00	5045	164	1367	6928	51	90	1540	267	2357	902	187	1244
Area 17-1985	47	4.63	8.00	3.00	7.00	5790	62	2094	8072	58	60	964	96	1173	1039	379	1420
Area 17-1986	32	5.13	6.00	2.00	6.75	4011	60	1015	6818	61	100	968	73	1746	760	191	1325

Table 6 (cont'd).

		Egg layers				Sample weight (g)				% cover		Obs. density			Pred. density		
	N	Mean	Mode	Q1	Q3	Mean	Mode	Q1	Q3	Mean	Mode	Mean	Q1	Q3	Mean	Q1	Q3
Foliose Red Algae																	
Area 14-1981	55	1.24	1.00	0.50	2.00	1093	306	566	1502	55	80	138	17	186	150	75	198
Area 14-1983	69	0.90	1.00	0.25	1.00	948	676	342	1267	36	25	151	15	241	174	43	221
Area 14-1985	32	0.94	1.00	0.25	1.00	1486	16	530	1626	41	40	194	19	140	205	57	199
Area 14-1986	25	1.32	0.50	0.40	2.25	1690	372	640	2615	58	50	308	77	541	223	85	338
Area 17-1985	20	0.36	0.10	0.10	0.47	1076	110	436	1785	75	100	123	13	202	117	41	198
Area 17-1986	3	1.02	0.25	0.25	2.00	1363	362	362	2092	83	65	356	12	563	185	39	266
Filamentous Red Algae																	
Area 14-1981	54	1.84	0.10	0.45	3.25	1585	117	172	1836	47	30	324	4	259	277	25	305
Area 14-1983	117	1.17	0.10	0.20	2.00	745	9	155	1076	30	10	96	5	131	138	24	200
Area 14-1985	62	2.10	0.10	0.50	3.12	2943	10	731	4944	57	100	569	35	986	494	90	855
Area 14-1986	139	1.94	1.00	0.80	2.30	2445	812	850	3302	62	100	668	109	951	404	129	531
Area 17-1985	22	1.94	0.50	0.50	2.62	2140	76	937	2904	63	100	238	13	365	353	141	484
Area 17-1986	10	4.63	1.00	1.00	7.00	2152	306	627	2715	57	50	556	138	753	422	87	558

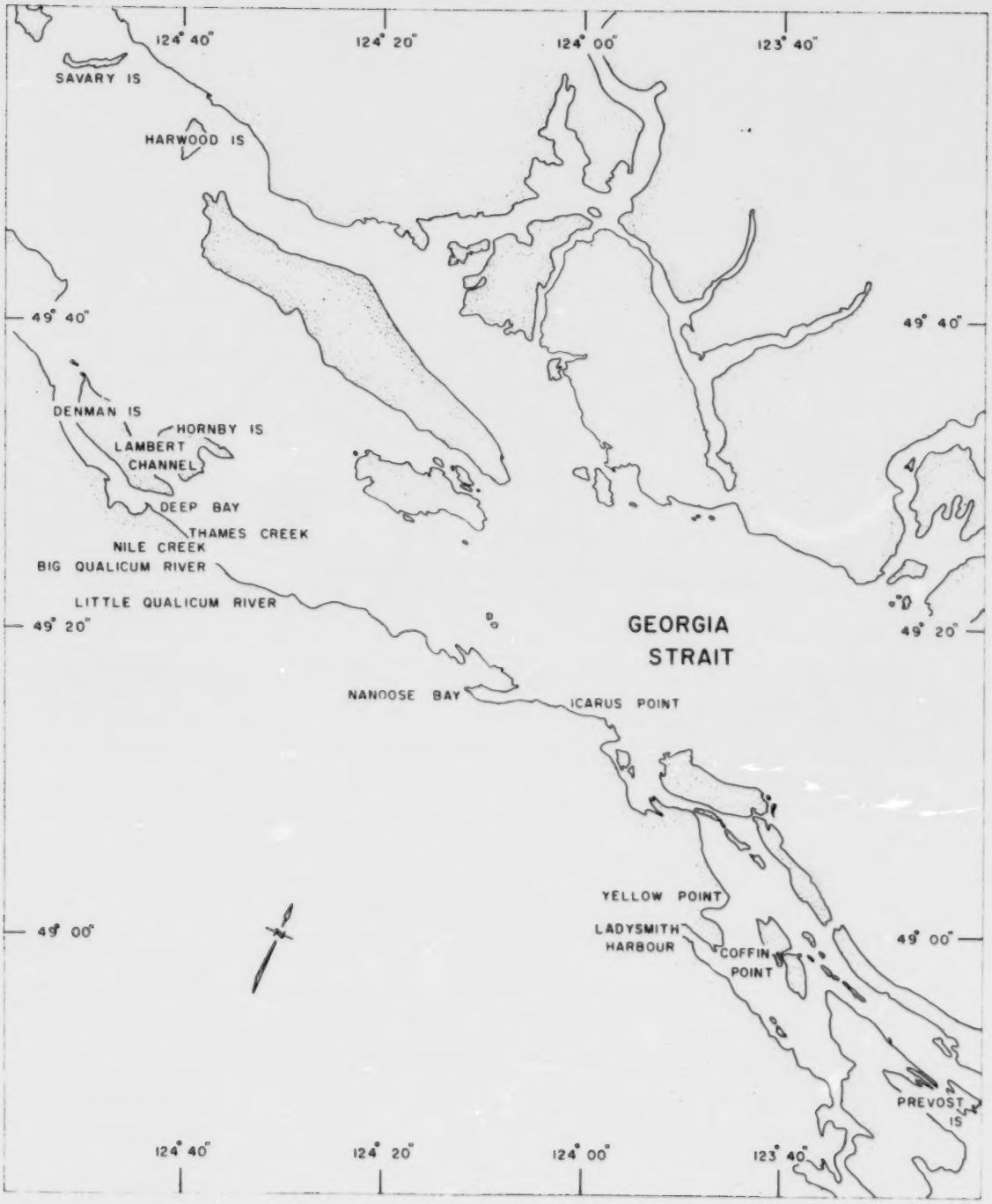


Fig. 1. Strait of Georgia herring spawn study area with major spawning locations identified.

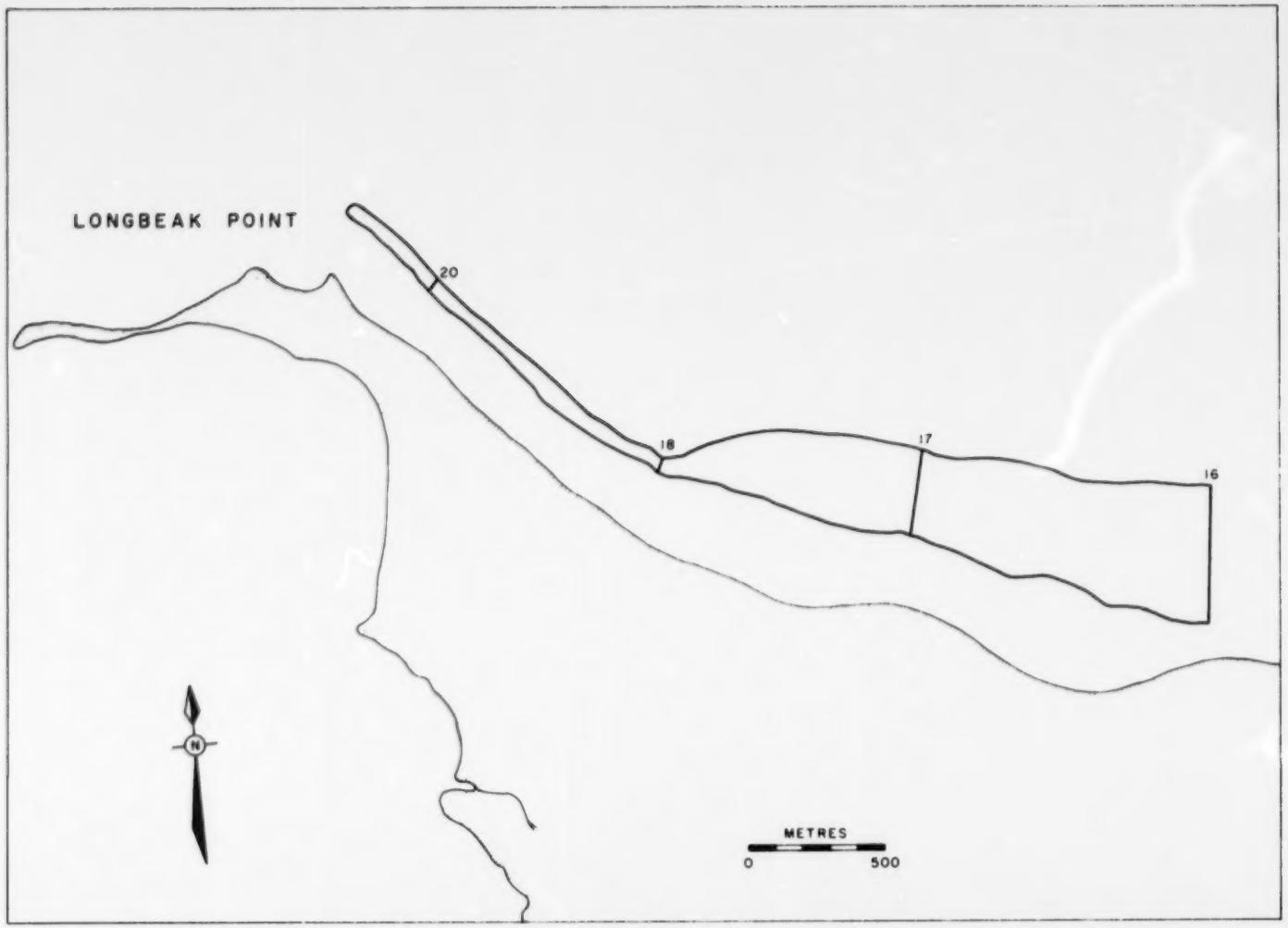


Fig. 2. Herring spawn at Longbeak Point on Denman Island, surveyed by divers in 1986, with transect locations shown.

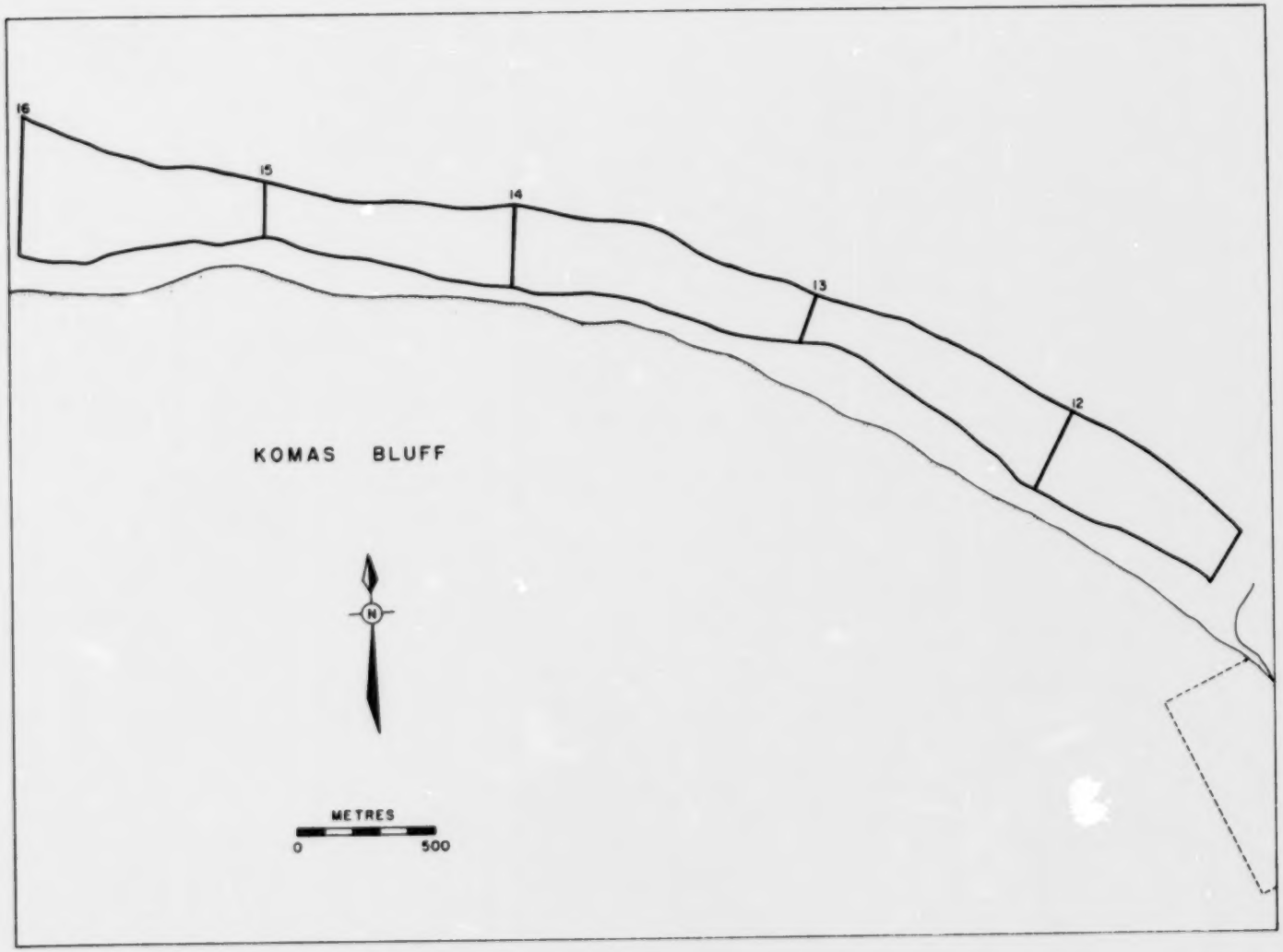


Fig. 3. Herring spawn at Komas Bluff on Denman Island, surveyed by divers in 1986, with transect locations shown.

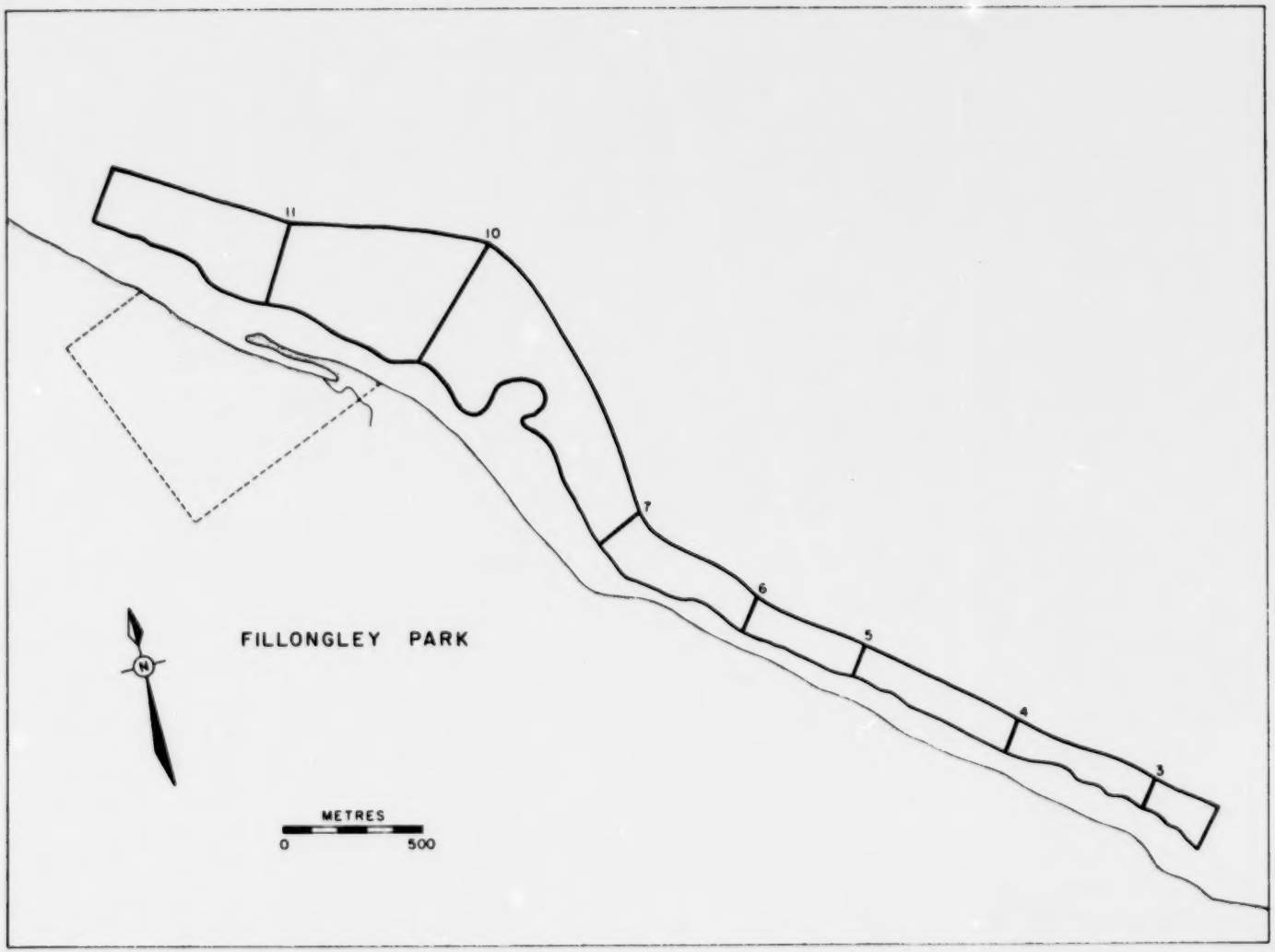


Fig. 4. Herring spawn at Fillongley Park on Denman Island, surveyed by divers in 1986, with transect locations shown.

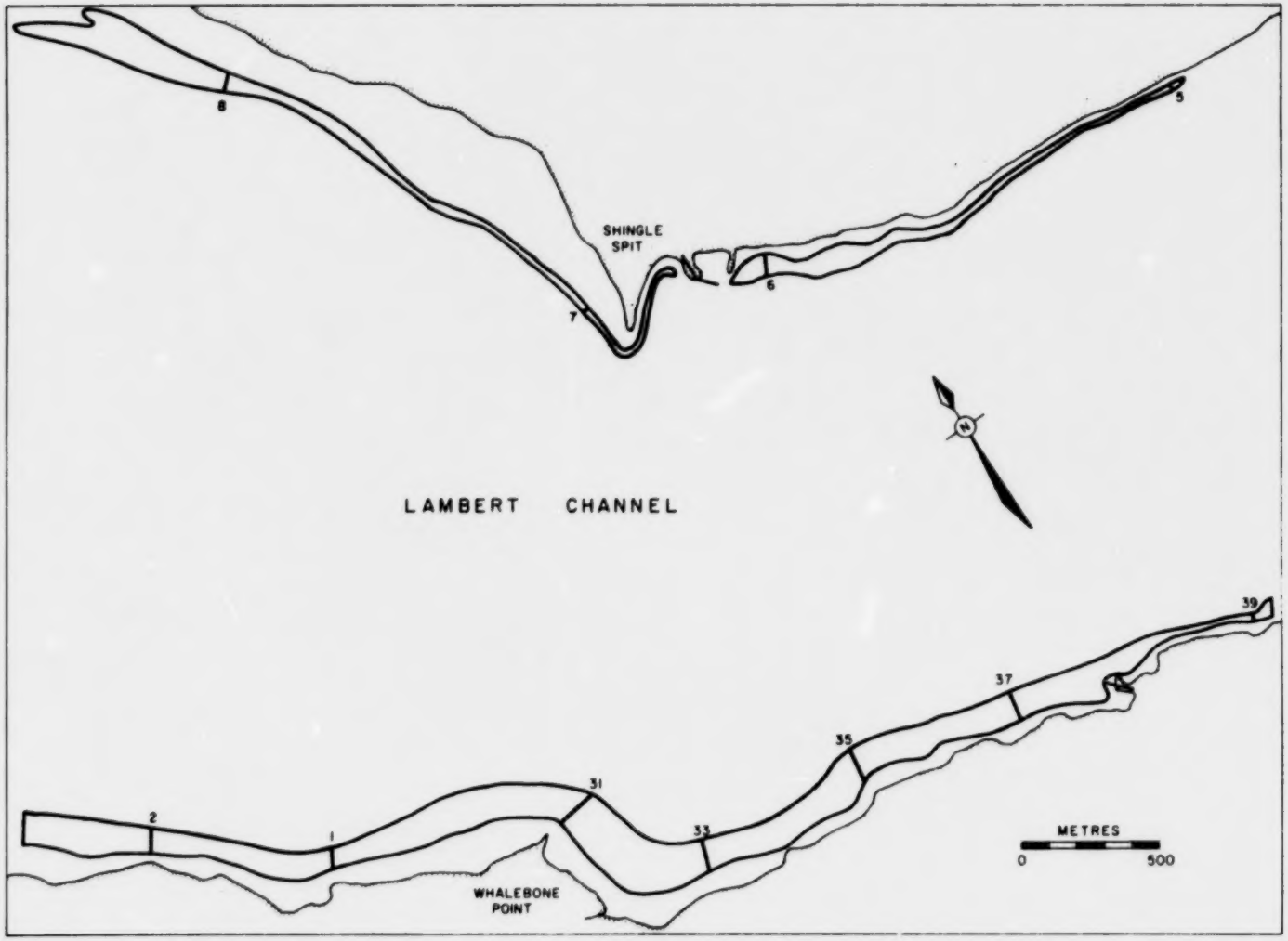


Fig. 5. Herring spawn in Lambert Channel including the spawn on both Denman and Hornby islands, surveyed by divers in 1986, with transect locations shown.

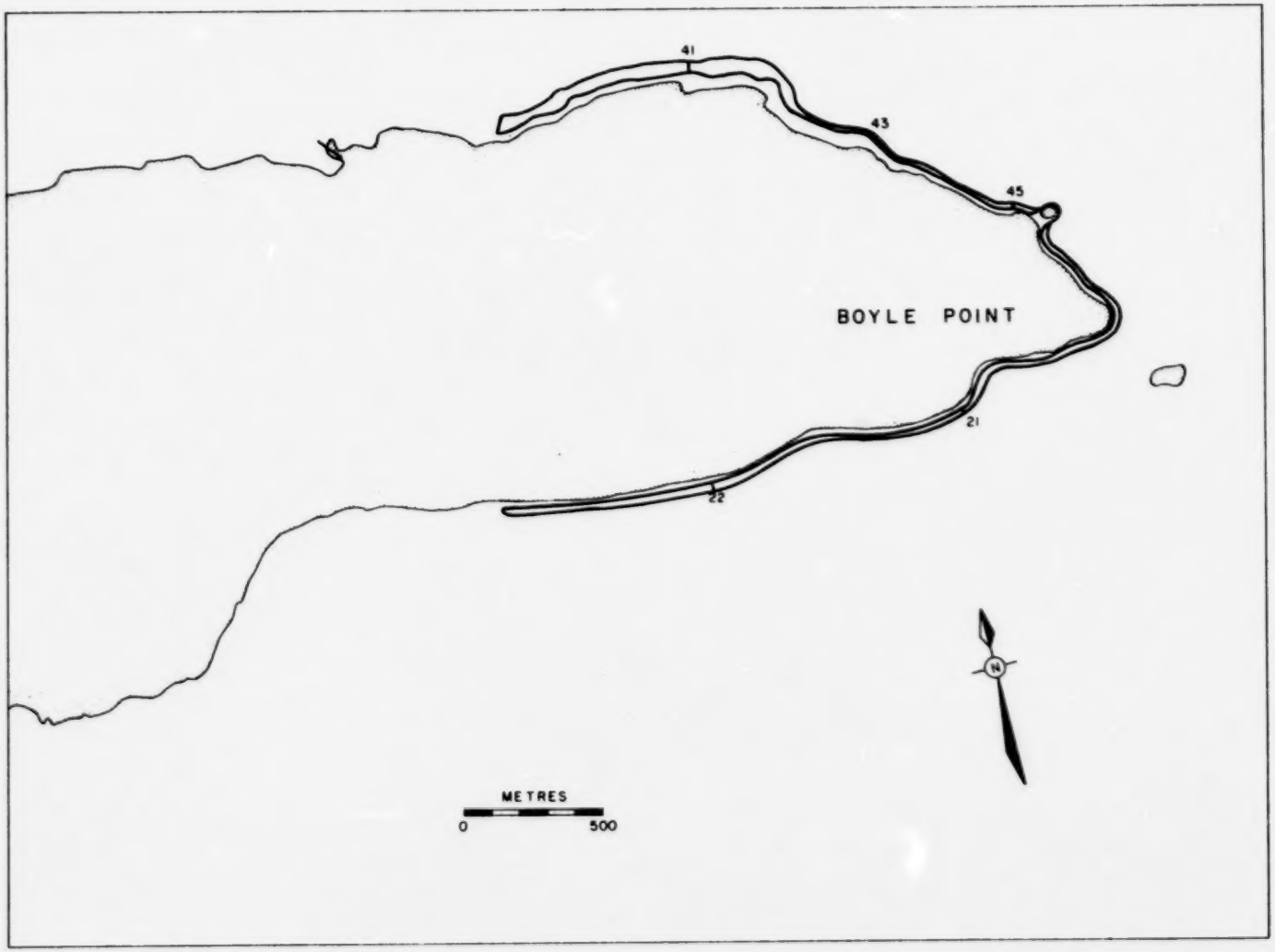


Fig. 6. Herring spawn at Boyle Point on Denman Island, surveyed by divers in 1986, with transect locations shown.

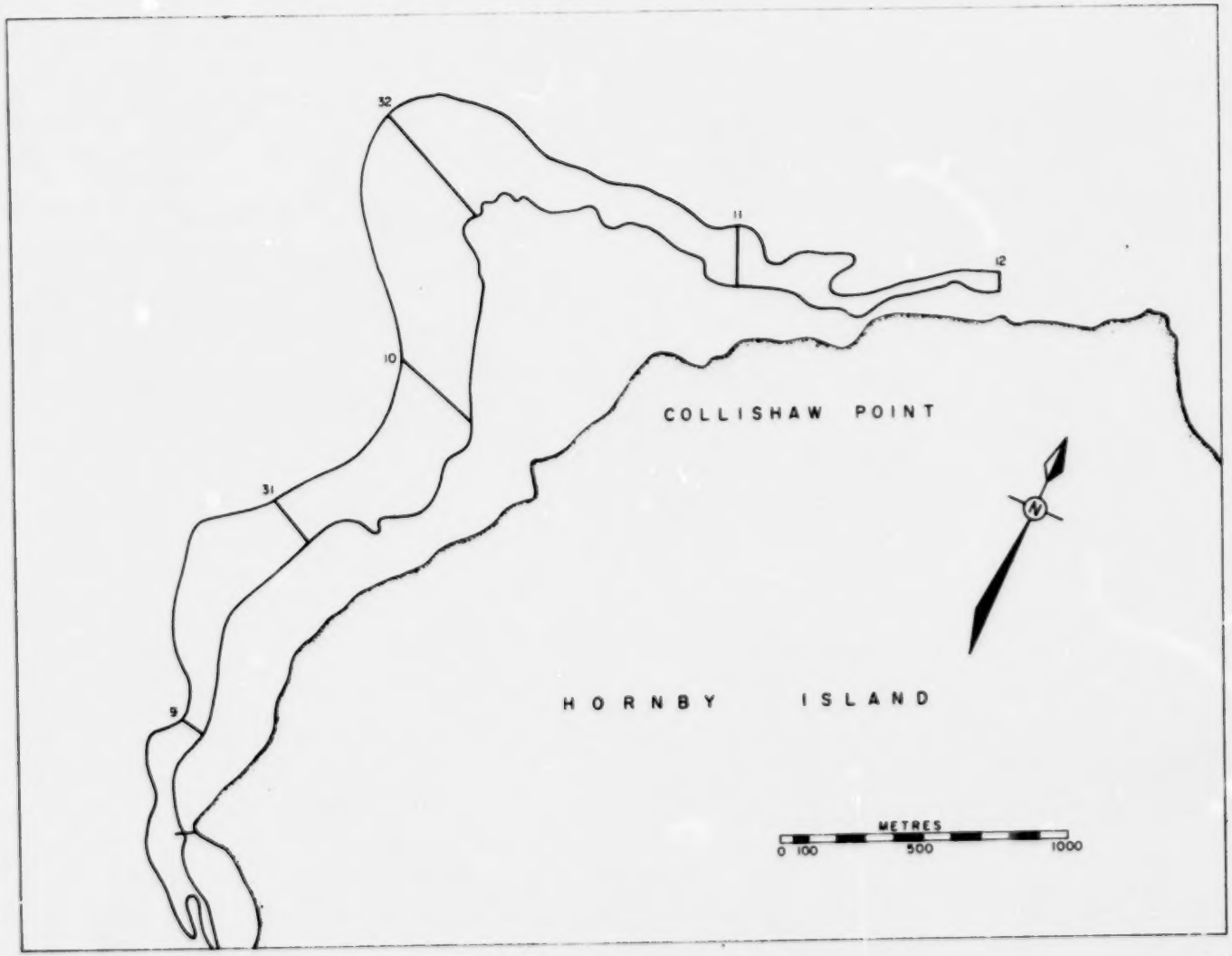


Fig. 7. Herring spawn at Collishaw Point on Hornby Island, surveyed by divers in 1986, with transect locations shown.

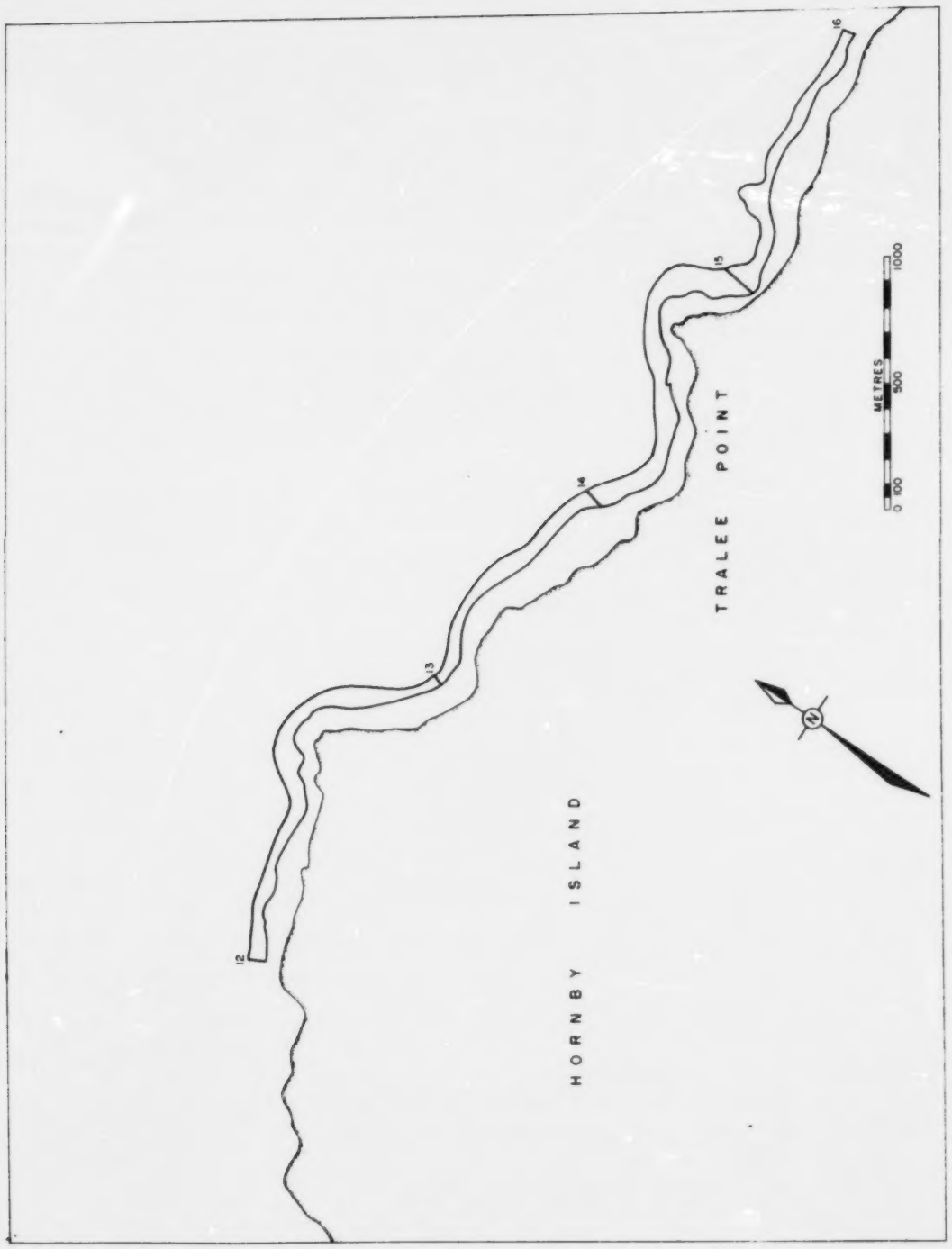


Fig. 8. Herring spawn at Tralee Point on Hornby Island, surveyed by divers in 1986, with transect locations shown.

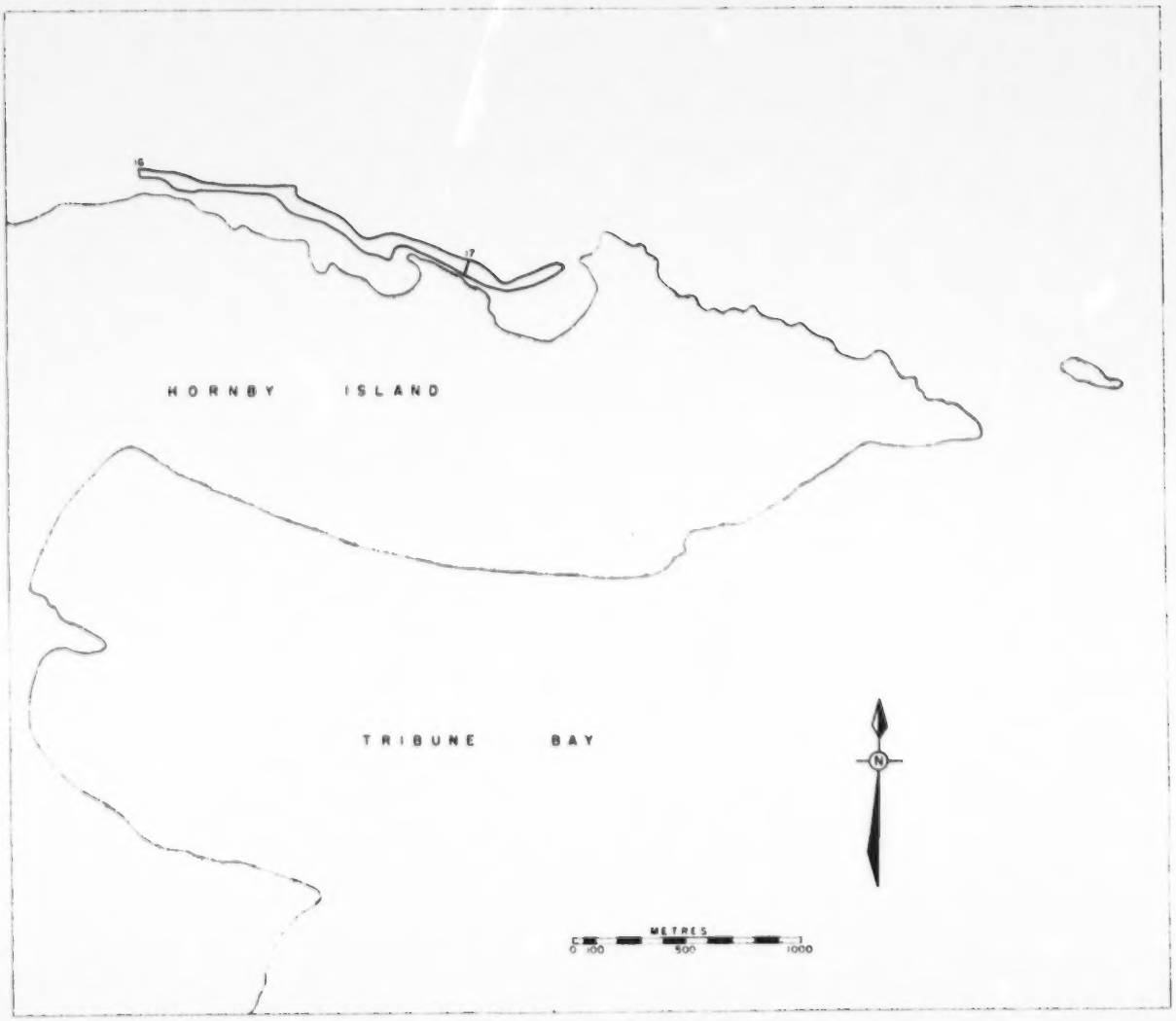


Fig. 9. Herring spawn at Whaling Station Bay on Hornby Island, surveyed by divers in 1986, with transect locations shown.

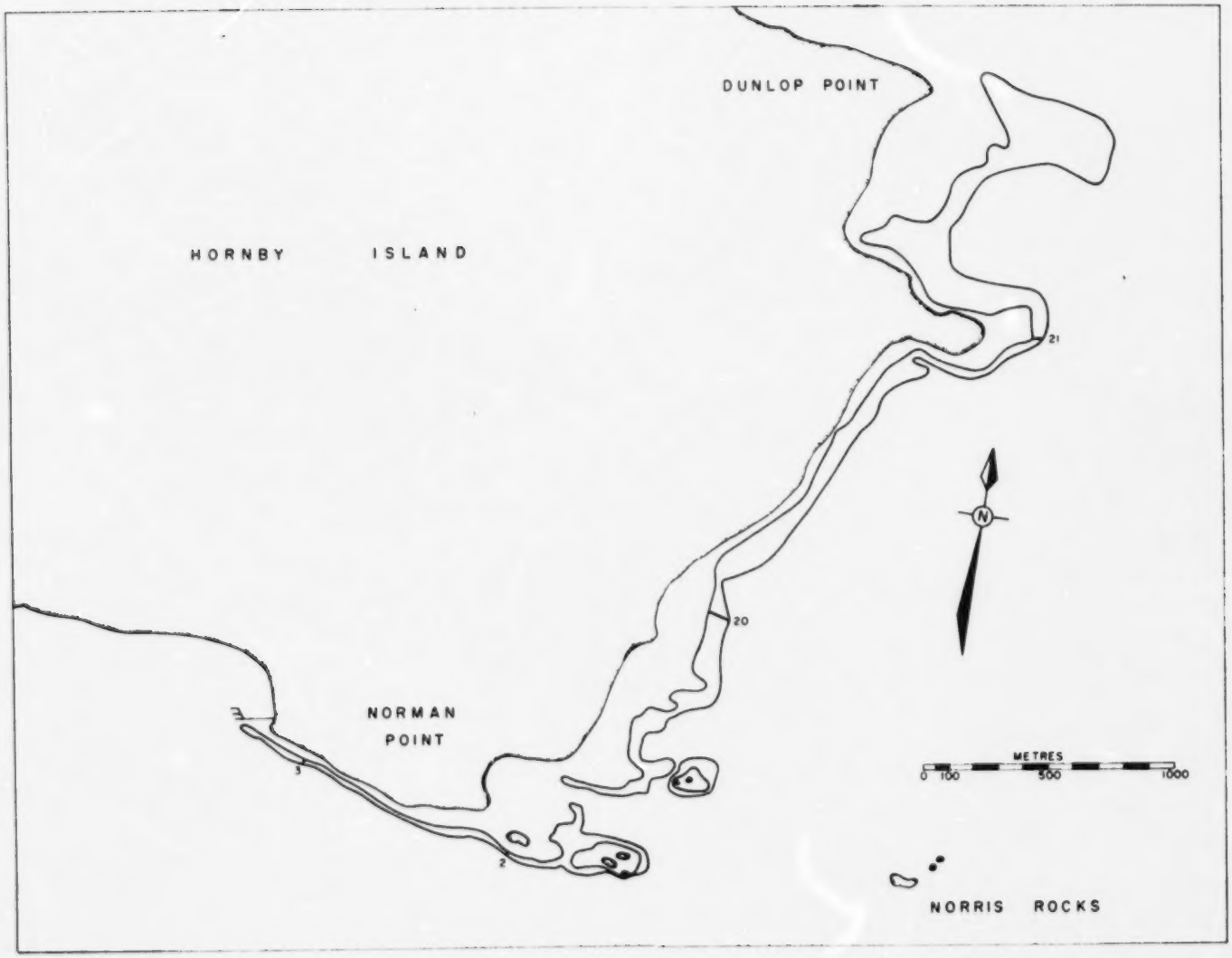


Fig. 10. Herring spawn from Norman Point to Dunlop Point on Hornby Island, surveyed by divers in 1986, with transect locations shown.

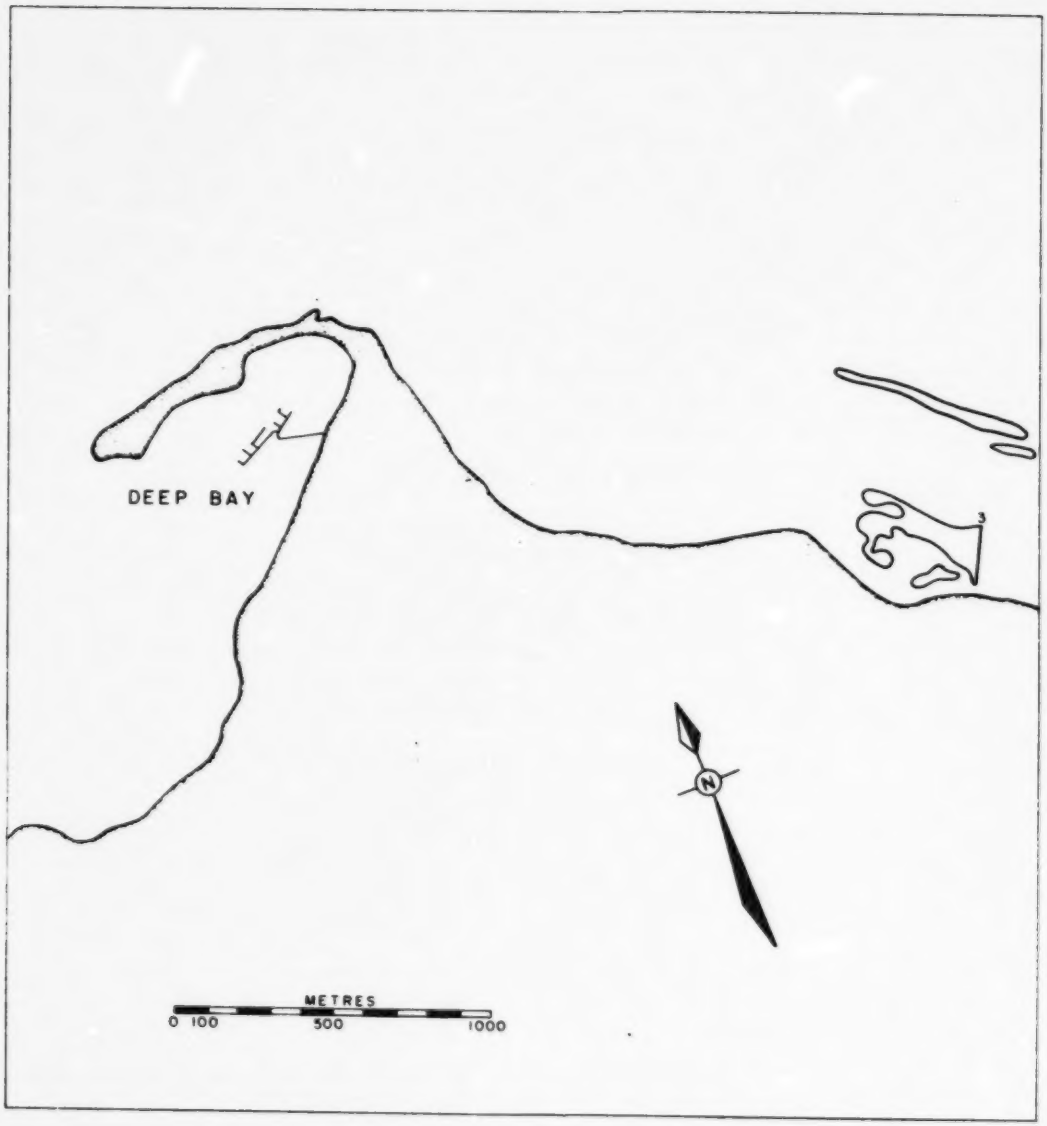


Fig. 11. Herring spawn at Deep Bay on Vancouver Island, surveyed by divers in 1986, with transect locations shown.

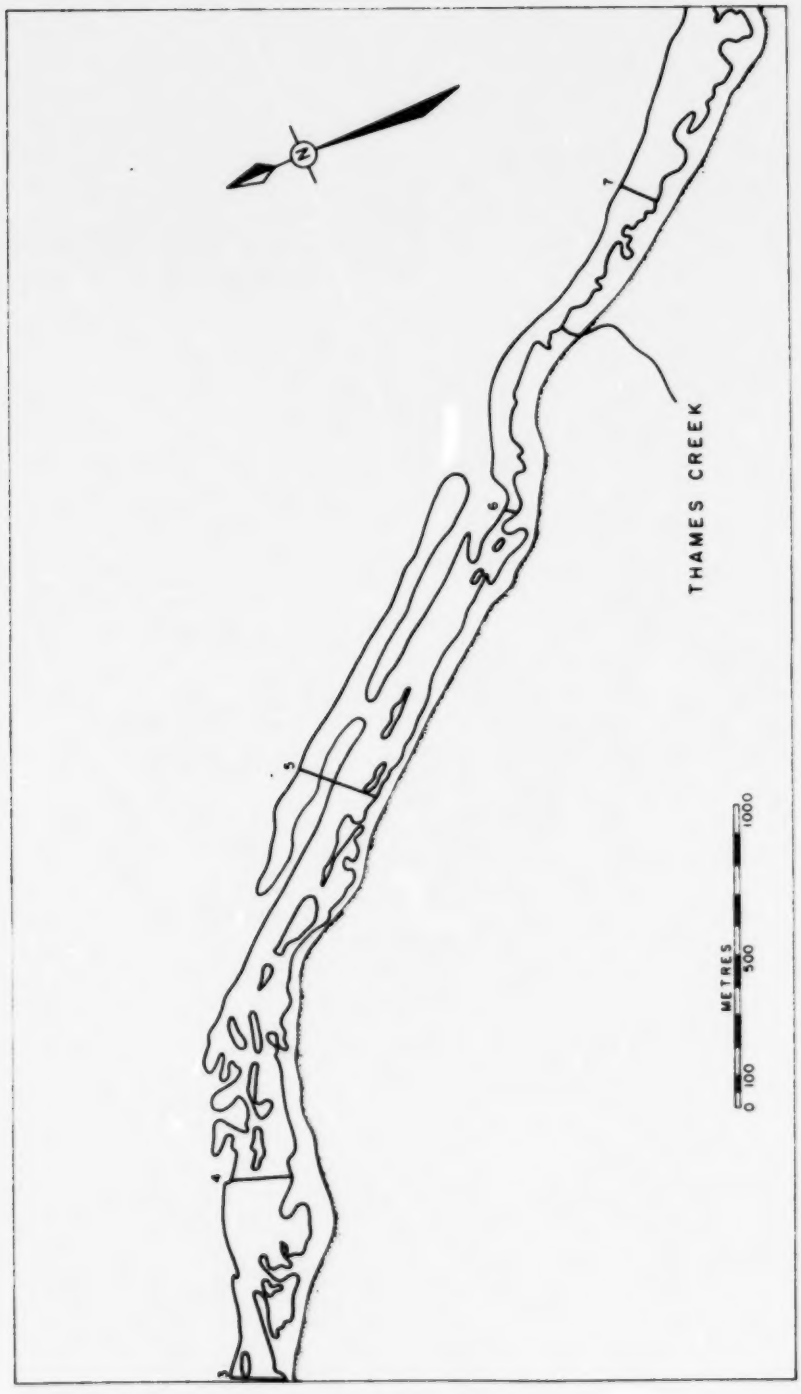


Fig. 12. Herring spawn at Thomas Creek near Bowser, surveyed by divers in 1986, with transect locations shown.

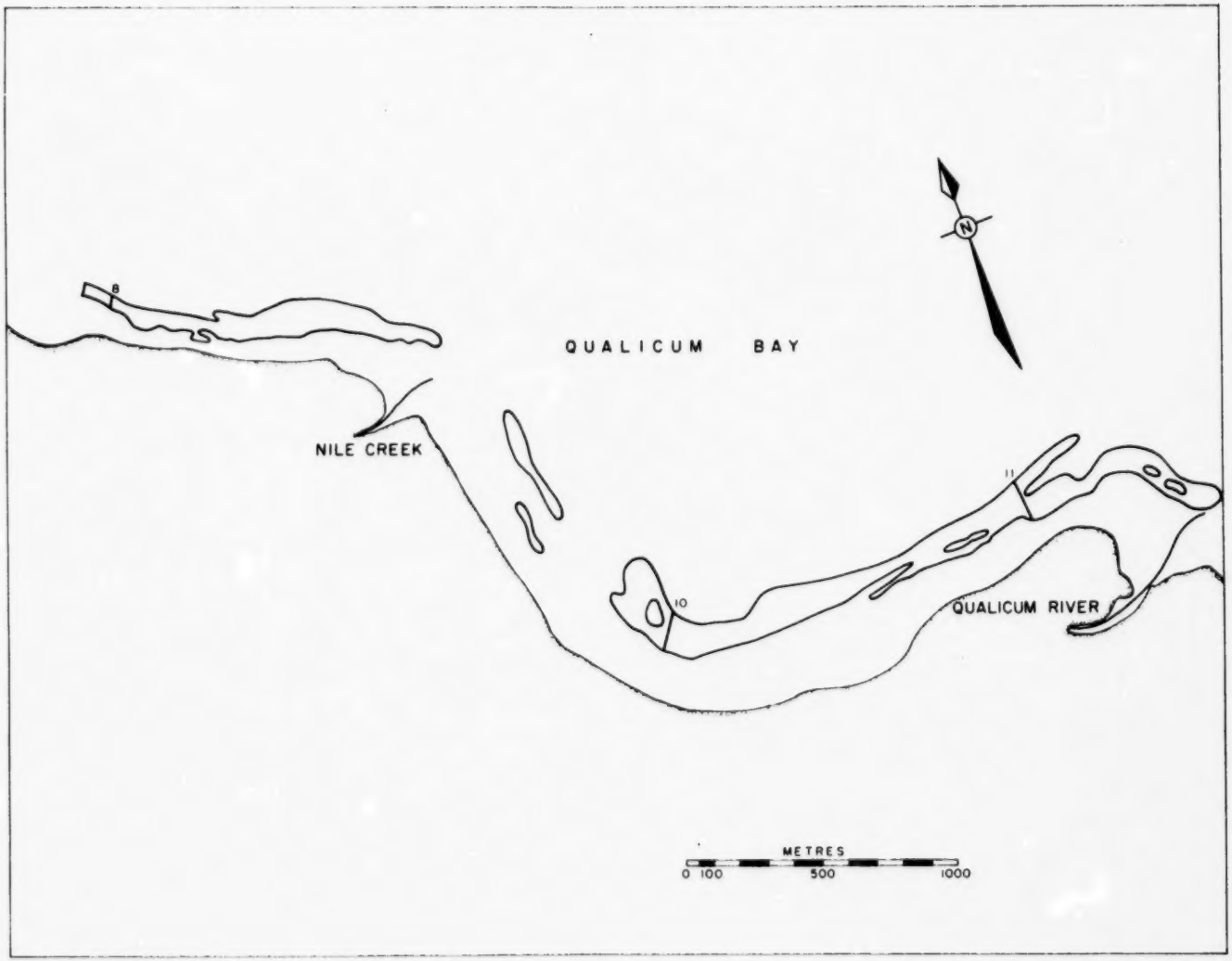


Fig. 13. Herring spawn from Nile Creek to Qualicum River, surveyed by divers in 1986, with transect locations shown.

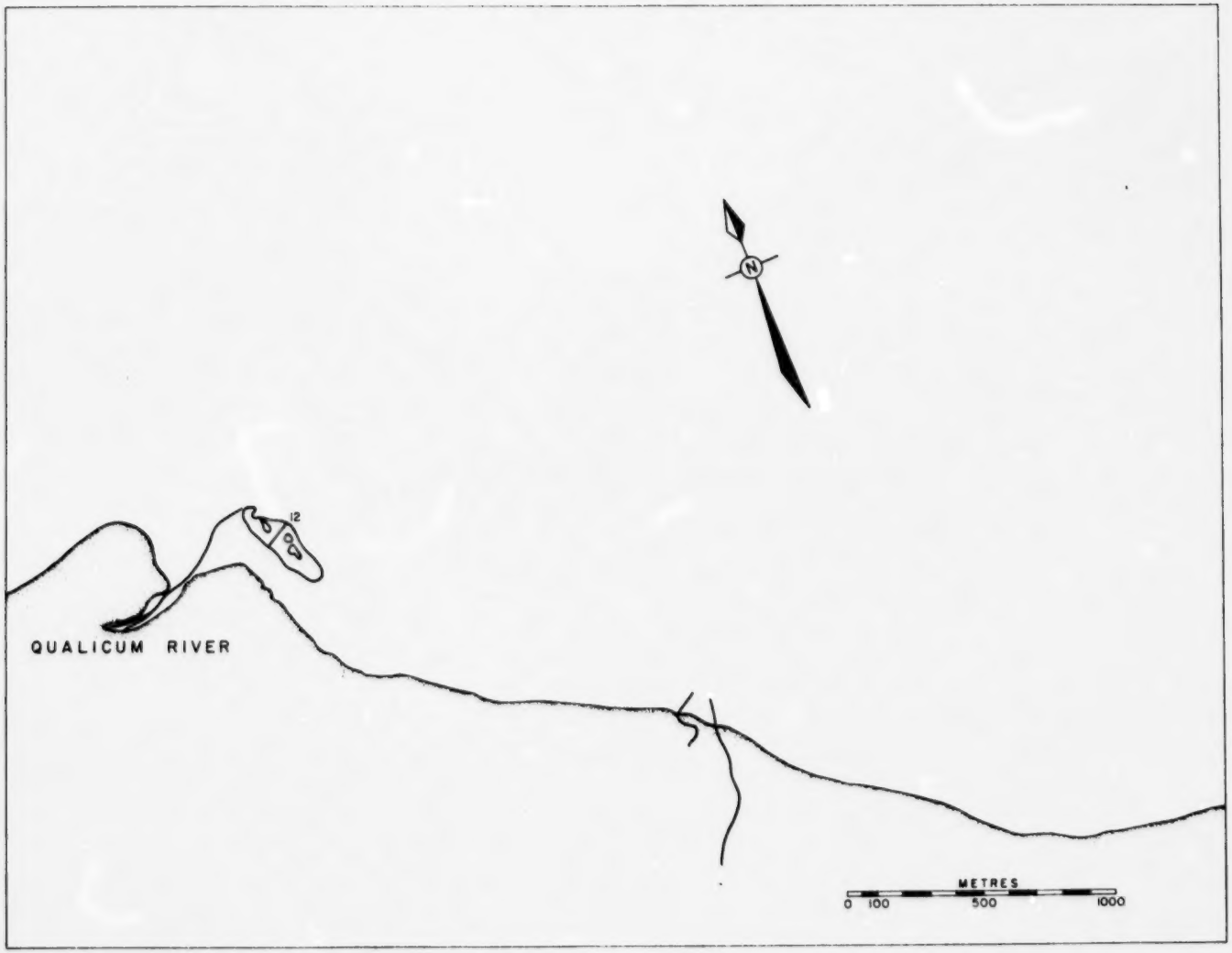


Fig. 14. Herring spawn near the Big Qualicum River, surveyed by divers in 1986, with transect locations shown.

Fig. 15. Herring spawn just west of the Little Qualicum River, surveyed by divers in 1986, with transect locations shown.

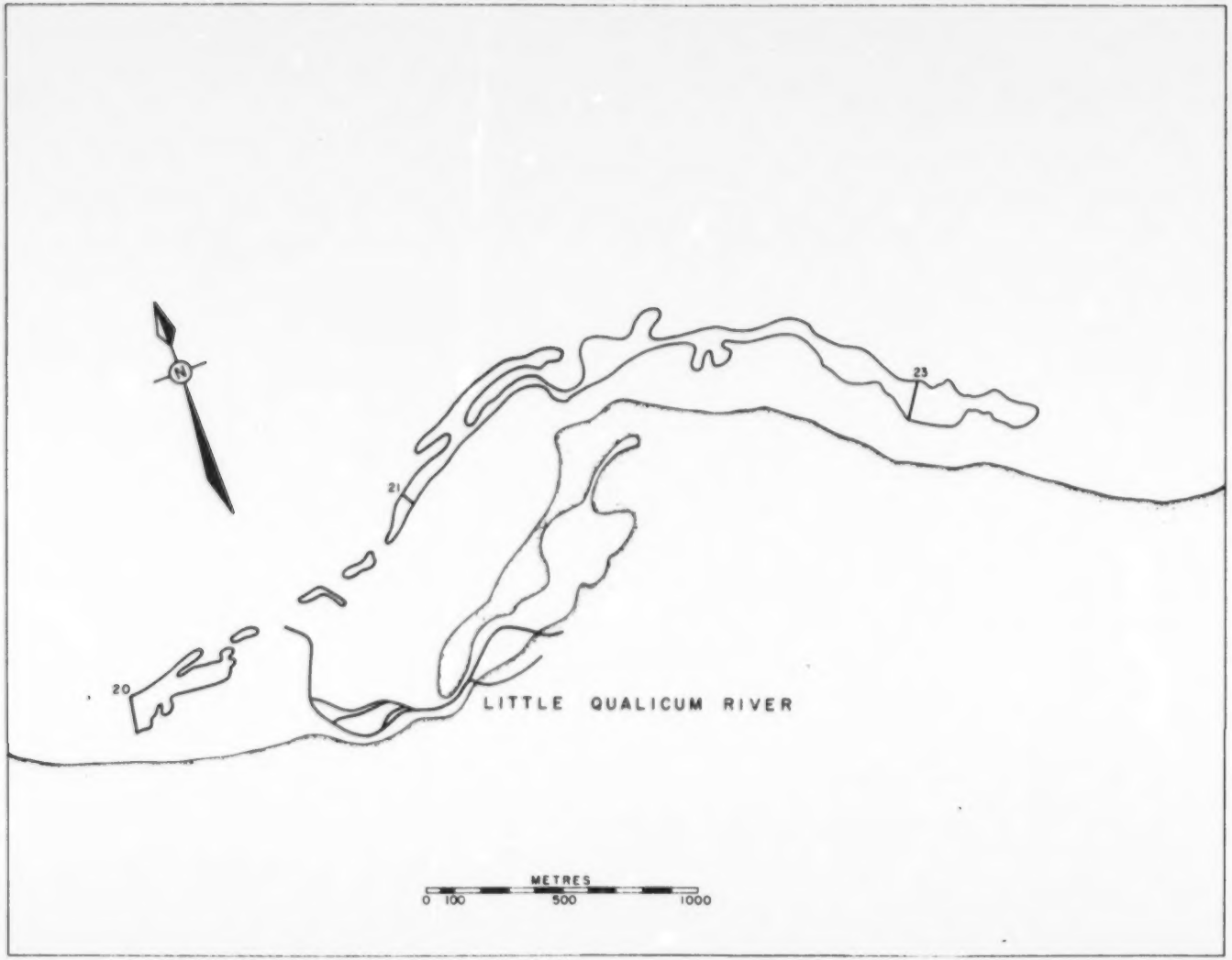


Fig. 16. Herring spawn at the Little Qualicum River, surveyed by divers in 1986, with transect locations shown.

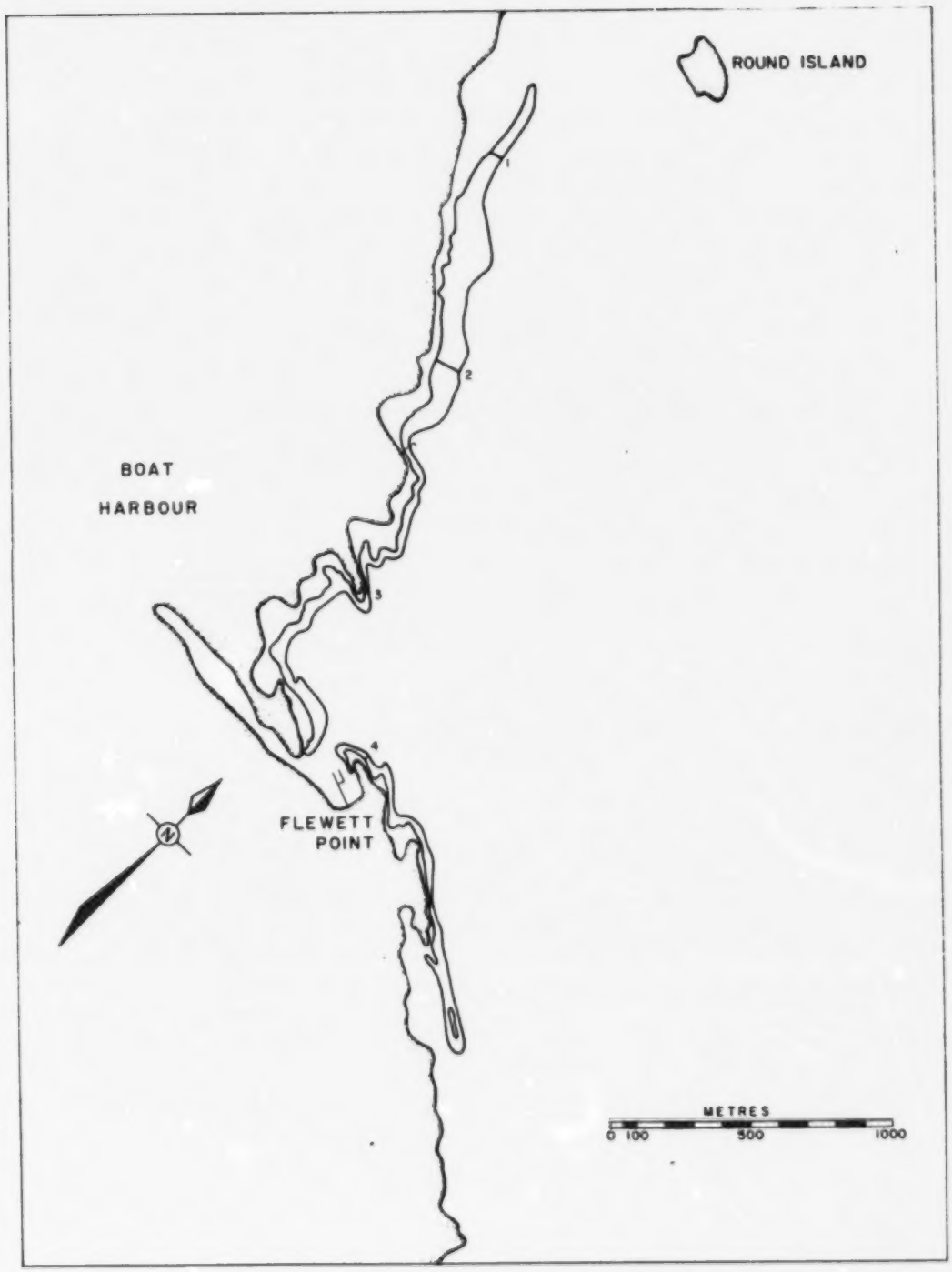


Fig. 17. Herring spawn from Round Island to Boat Harbour in Stuart Channel, surveyed by divers in 1986, with transect locations shown.

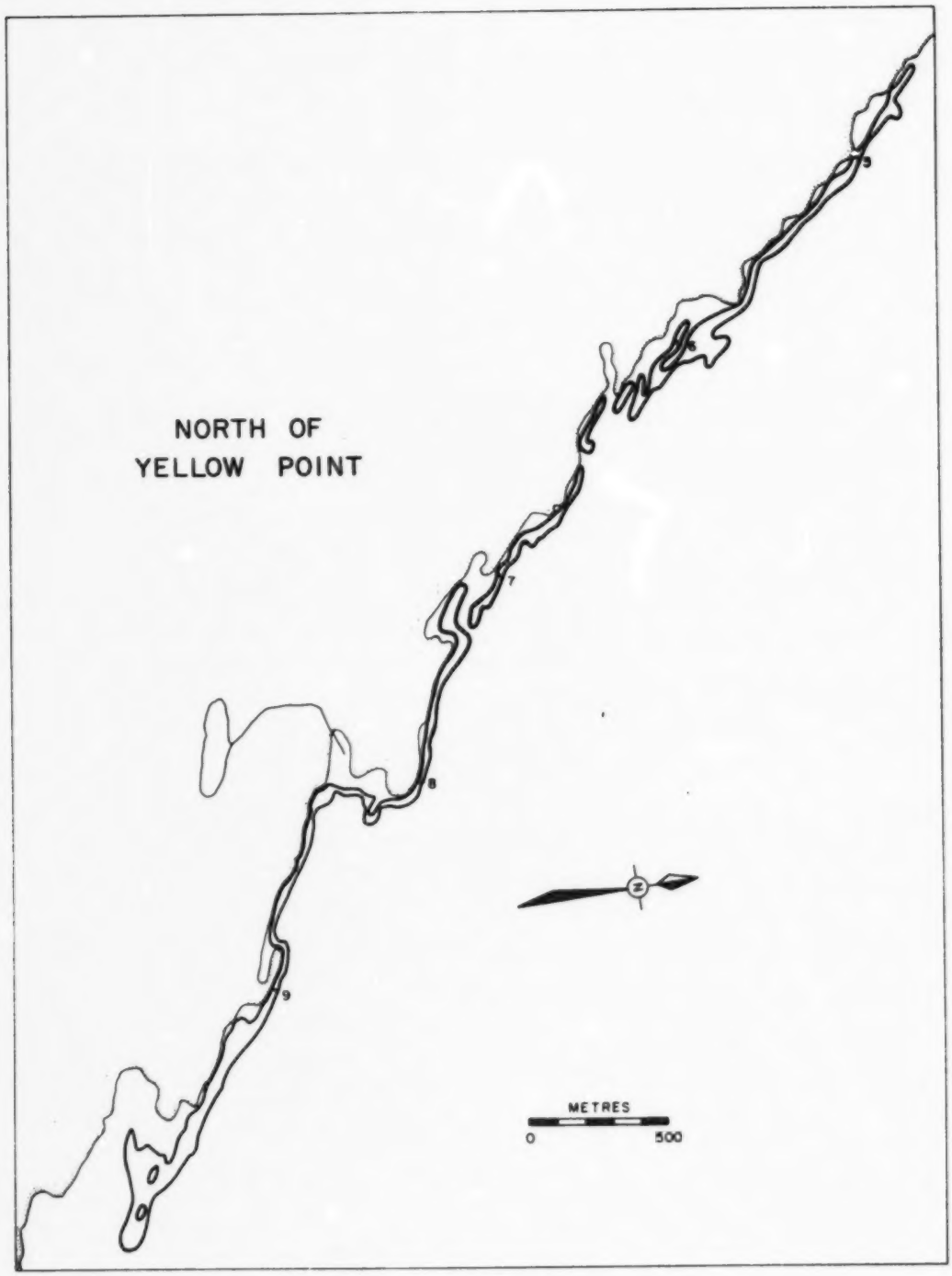


Fig. 18. Herring spawn north of Yellow Point in Stuart Channel, surveyed by divers in 1986, with transect locations shown.

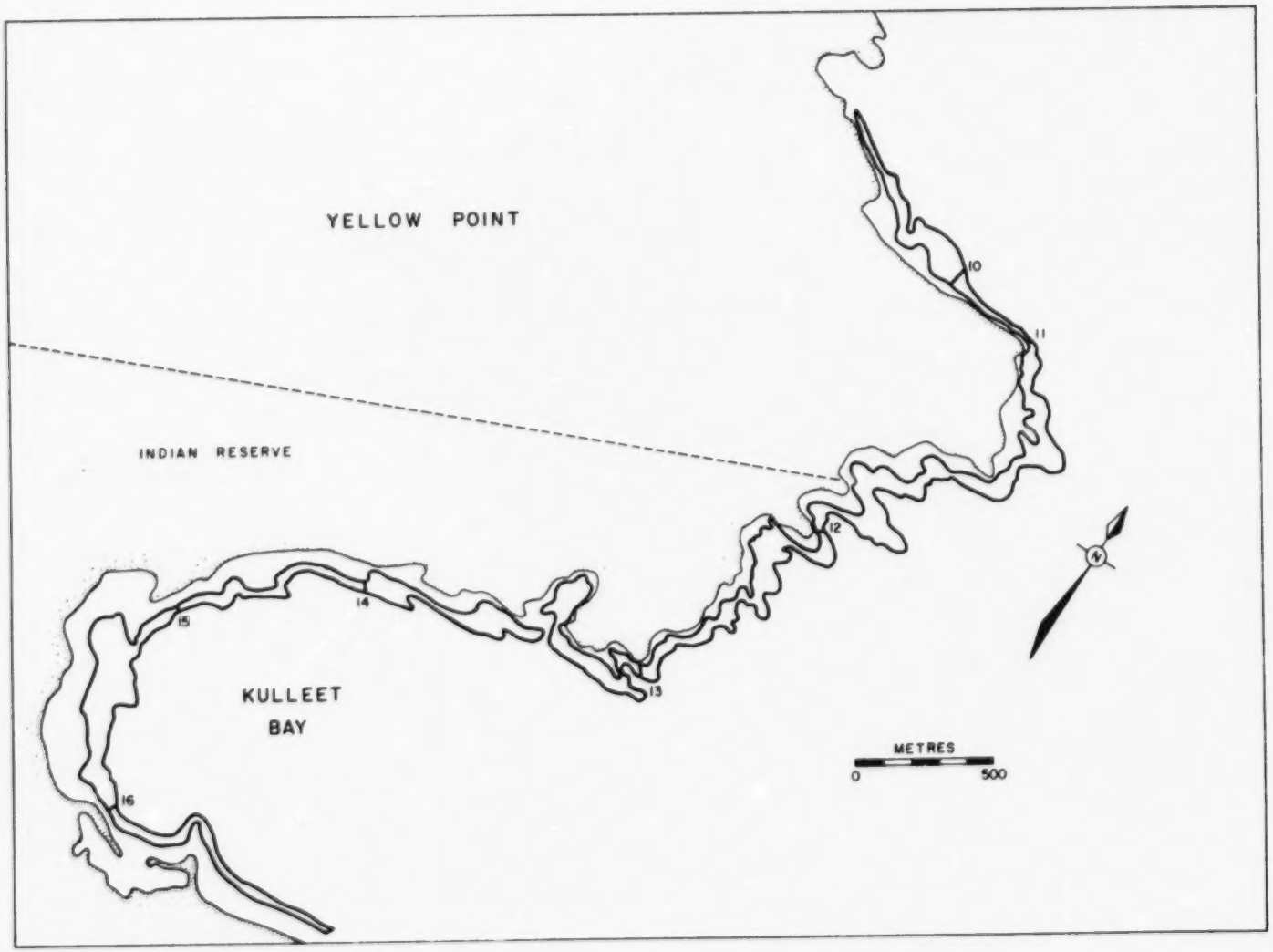


Fig. 19. Herring spawn from Yellow Point to Kulleet Bay, surveyed by divers in 1986, with transect locations shown.

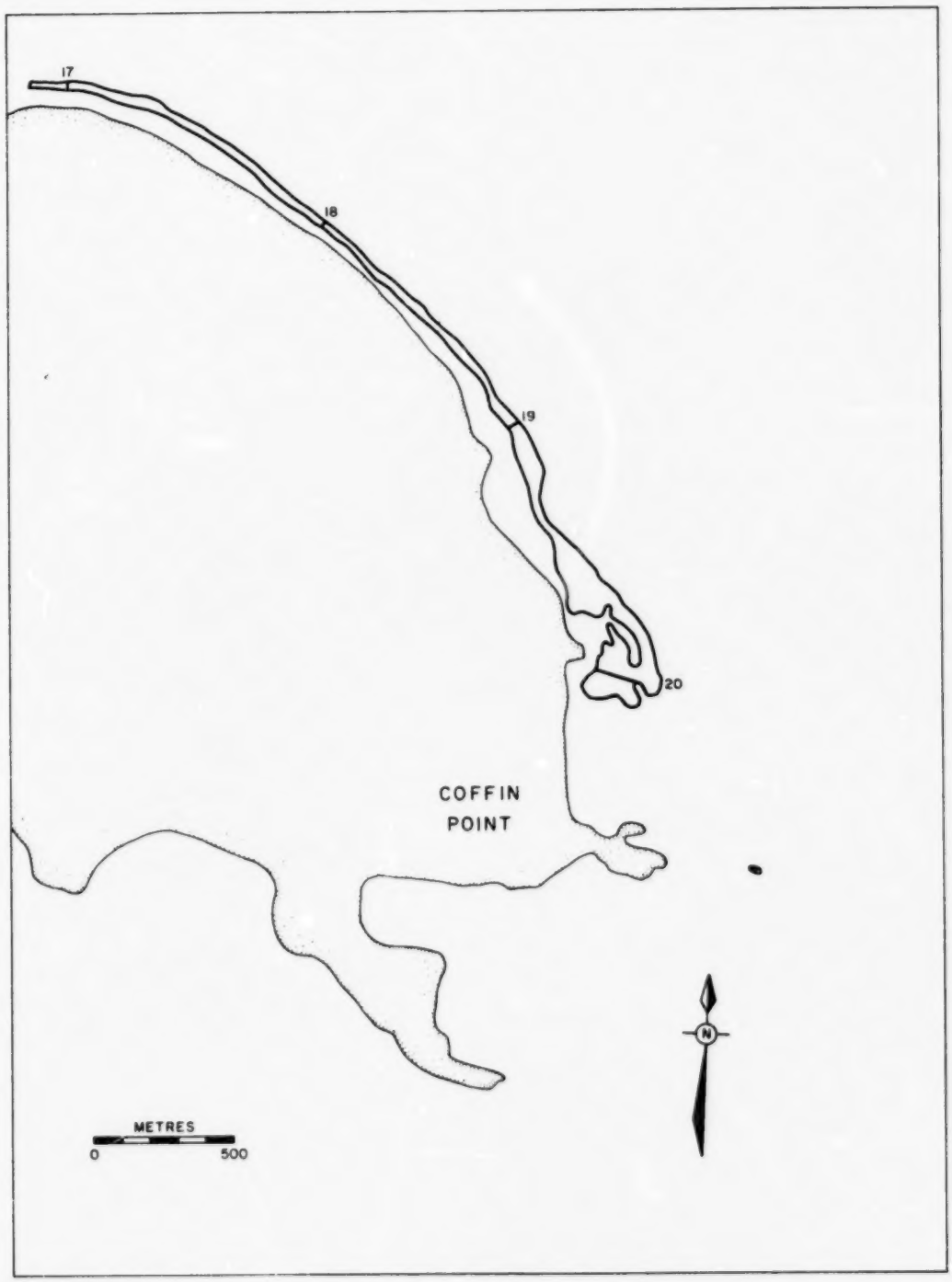


Fig. 20. Herring spawn from Kulleet Bay to Coffin Point, surveyed by divers in 1986, with transect locations shown.

Fig. 21. Physical description of transects along which spawn survey information was collected by divers in 1986 in Georgia Strait. Average (with 95% CI.I) transect lengths, beach slopes, depths above (+) and below (-) chart datum of outer edge of spawn (OES DEPTH) and inner edge of spawn (IES DEPTH) and no. of transects sampled are shown.

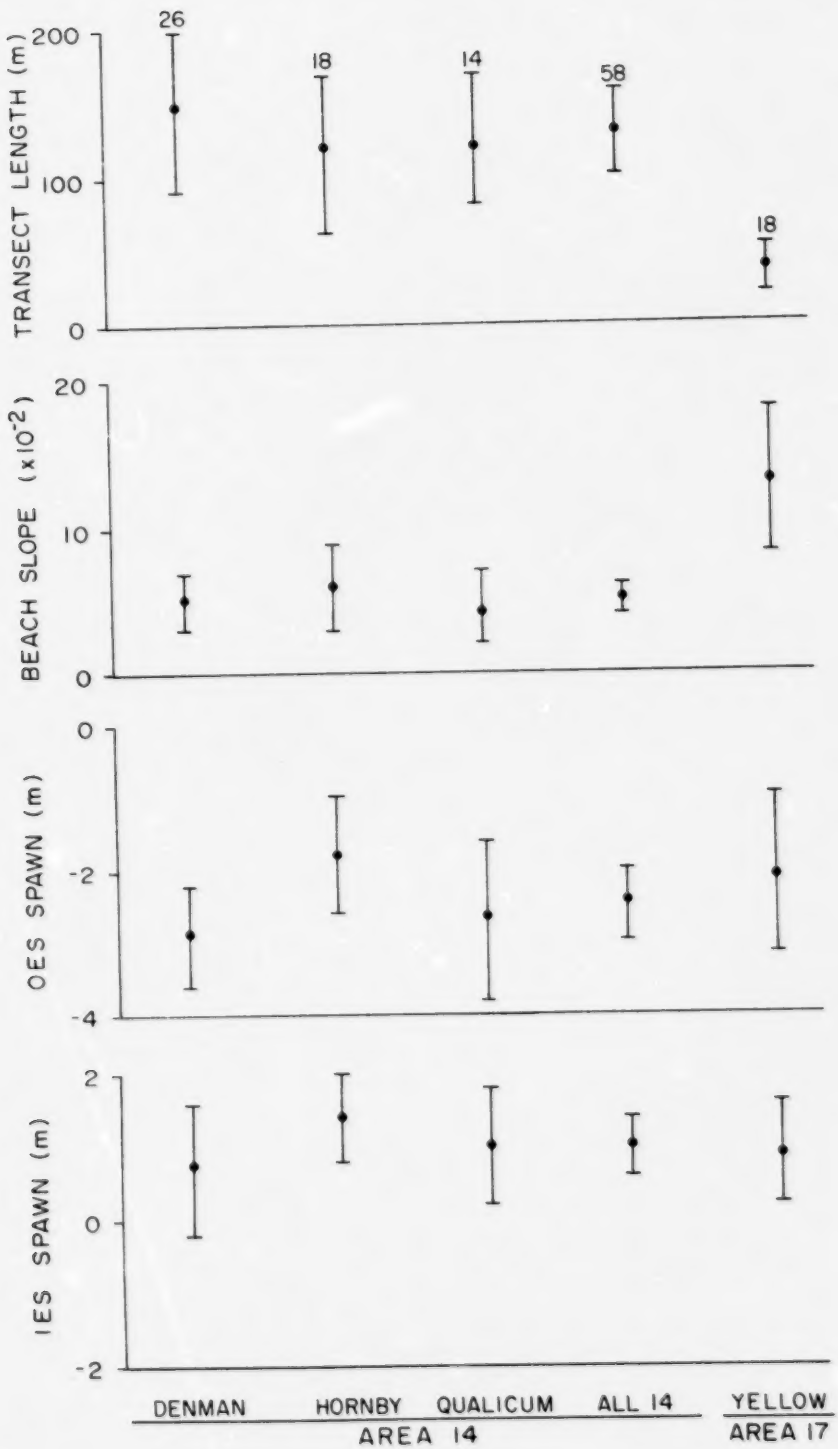

TRANSECT LENGTH (m)
200
100
0
26
18
14
58
18
BEACH SLOPE (x10⁻²)
20
10
0
OES SPAWN (m)
0
-2
-4
IES SPAWN (m)
2
0
-2
DENMAN
HORNBY
QUALICUM
ALL 14
AREA 14
YELLOW
AREA 17

Fig. 22. Dominant vegetation types upon which eggs were deposited in 1986, summarized by depth intervals [intertidal (above chart datum), upper subtidal (0 to 3 m below chart datum), and middle subtidal (3 to 6 m below chart datum)]. (SG = sea grasses, RW = rockweed, KE = kelp, OB = other brown algae, FO = foliose red algae, FI = filamentous red algae.)

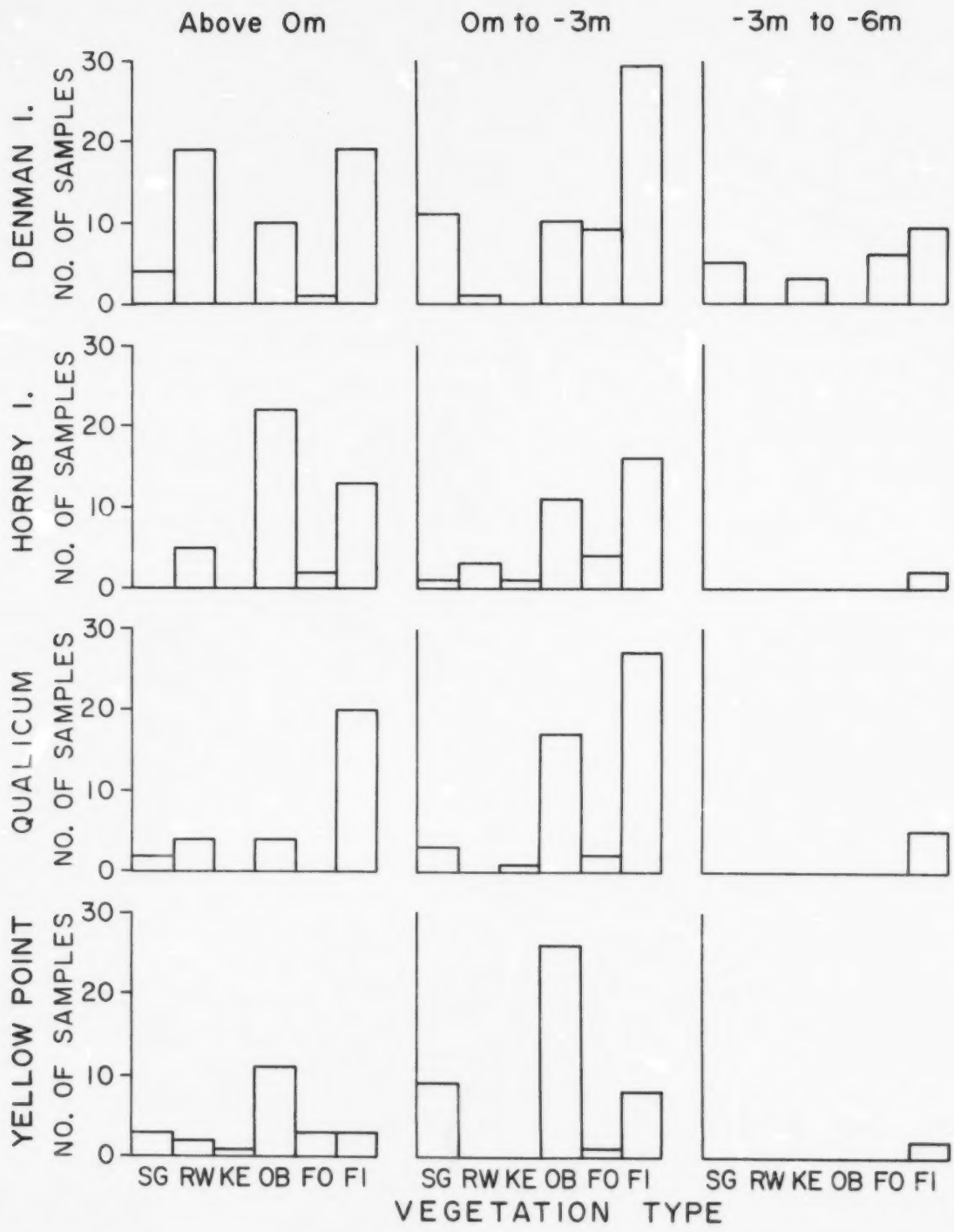

Above Om
Om to -3m
-3m to -6m
DENMAN I.
HORNBY I.
QUALICUM
YELLOW POINT
NO. OF SAMPLES
0
10
20
30
SG RW KE OB FO FI
VEGETATION TYPE

Fig. 23. Percent cover of vegetation, layers of eggs, eggs per sq. m, and sample weight (Wilcoxon median and 95% C.I.) by depth interval [intertidal (above chart datum), upper subtidal (0 to 3 m below chart datum), and middle subtidal (3 to 6 m below chart datum)] for spawns surveyed by divers in Georgia Strait in 1986. Sample numbers are shown above C.I. bar.

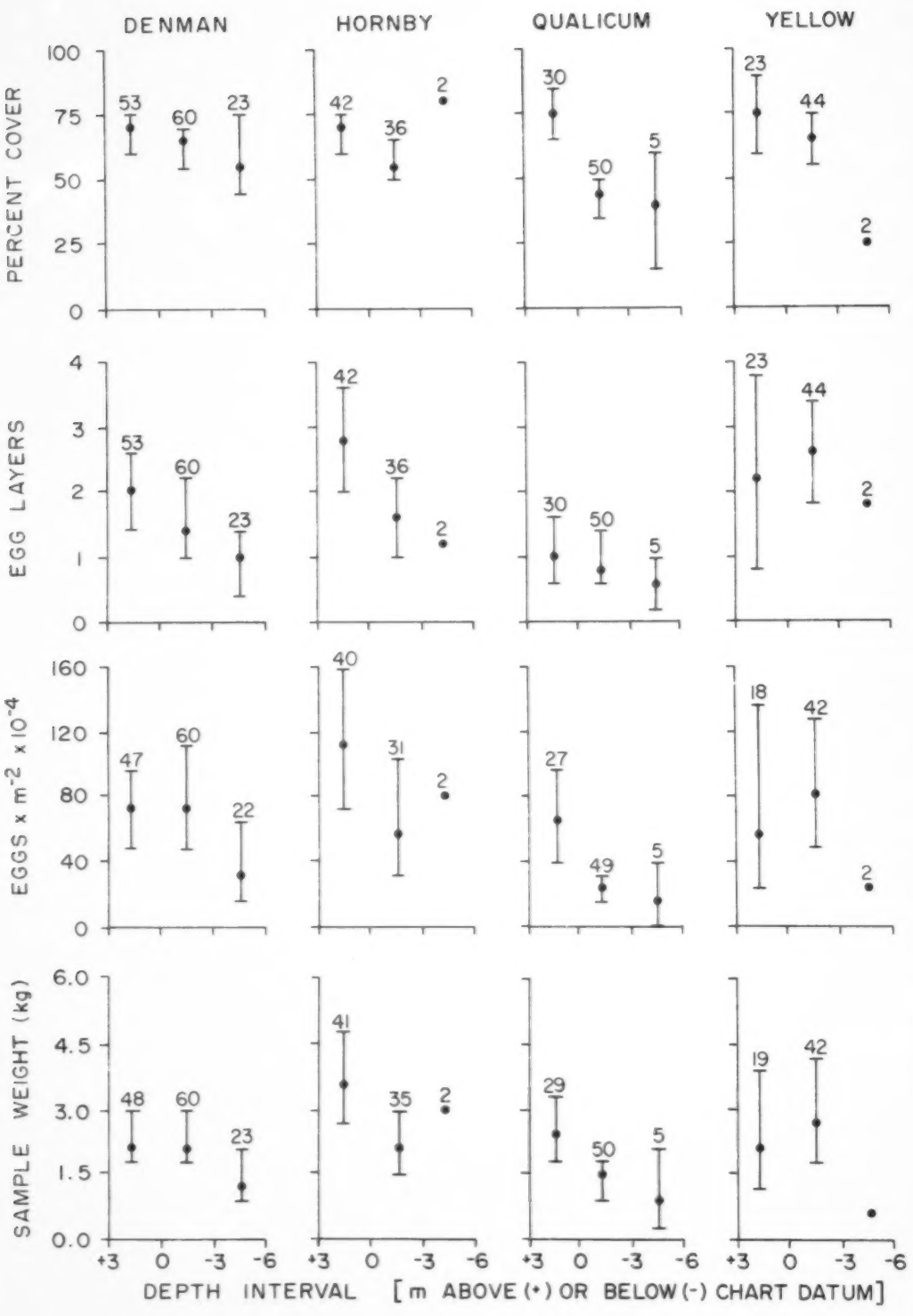
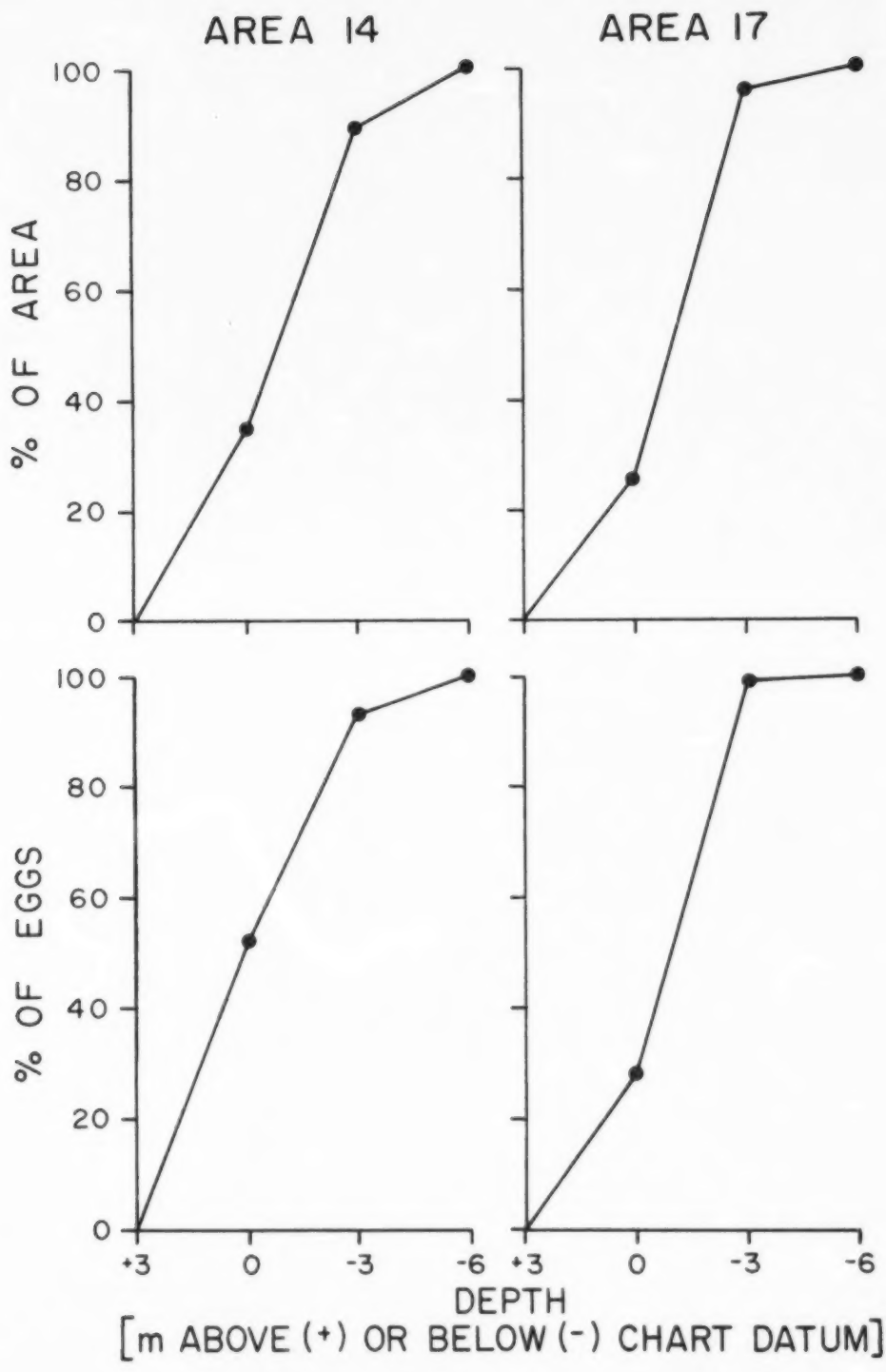

DENMAN
HORNBY
QUALICUM
YELLOW
PERCENT COVER
EGG LAYERS
EGGS x m⁻² x 10⁻⁴
SAMPLE WEIGHT (kg)
DEPTH INTERVAL [m ABOVE (+) OR BELOW (-) CHART DATUM]
+3 0 -3 -6

Fig. 24. Distribution of spawn area and eggs by depth interval [intertidal (above chart datum), upper subtidal (0 to 3 m below chart datum), and middle subtidal (3 to 6 m below chart datum)] for spawns surveyed by divers in Georgia Strait in 1986.


AREA 14
AREA 17
% OF AREA
% OF EGGS
100
80
60
40
20
0
+3
0
-3
-6
DEPTH
[m ABOVE (+) OR BELOW (-) CHART DATUM]